ECONOMIC BOTANY

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Semi-Popular Articles 118

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Important Correction

See page 197 of this issue for corrections regarding Dr. Joseph's article on citrus products and Dr. Acosta-Solis' article on tagua in previous issues of ECONOMIC BOTANY.

The Coconut Palm—*Mankind's Greatest Provider in the Tropics*

Its stem and foliage furnish building material and thatching for the native, and the milk of its fruit gives him nourishment, while the meat of the fruit provides an edible delicacy and industrially important coconut oil for man in the Temperate Zones.

OSCAR K. MOORE[1]
U. S. Department of Agriculture

Introduction

THE coconut palm (*Cocos nucifera* L.), economically speaking, is the most important member of the palm family and grows throughout the humid tropics. It is one of the world's principal sources of food for both the natives of the tropics and people of the heavily populated temperate regions.

Many of us know coconut only in the shredded form, and its importance as a supplier of edible vegetable oil often is not realized. Vegetable oils are important in modern living and compete against animal-derived fats and oils. Large quantities are consumed in the manufacture of margarine, shortening, medicine, soaps, cosmetics, paints, lubricants, oenanthic ether—a flavoring for foods and beverages—and other products. Coconut oil, one of the leading vegetable oils, is extracted from copra, *i.e.*, the dried fleshy part of the coconut.

When the oil is pressed from copra, the fat-containing, cake-like residue is used for livestock feed. It is good for dairy cattle, for it adds butterfat to their milk, and hogs can be fattened on it. Coco-stearin is separated from the oil and used in the manufacture of candles.

All floating soaps were made from coconut oil until a few years ago when it was discovered that most soaps can be made to float by pumping air through the mixture during manufacture. Coconut oil is particularly adapted to soap manufacture because of its high lauric acid content, by virtue of which, soaps made from it are quick-lathering. Marine soaps that lather in hard water can be made from it and from no other oil. Coconut oil soaps thus are soluble in brine and suitable for use at sea.

The increasing current output of soap, margarine and other oil-derived products creates a heavy world demand for coconut oil, as a result of which, production of coconut in the tropics has been increased by scientific coconut farming. Large areas have been planted systematically with the palms, and commercial crops are produced under technical management. Yields running from 800 to 1,200 pounds of oil per acre are common from mature palms on large foreign-supervised plantations. This is about twice the yield from small native-operated groves comprising planted and natural stands. However, from 80 to 90

[1] The author is indebted to the following staff members of the Department of Agriculture who reviewed and made suggestions regarding this manuscript: Dr. D. F. Cook (now retired) and Dr. H. R. Fulton, Bureau of Plant Industry, Soils, and Agricultural Engineering, and Regina H. Boyle, Office of Foreign Agricultural Relations. The author is indebted to Hally H. Conrad, Editor of "Foreign Agriculture", Office of Foreign Agricultural Relations, for suggestions and assistance in the preparation of the manuscript.

percent of the world's coconut production comes from native-operated groves, and about half the world output comes from palms not cultivated.

The various parts of the coconut palm are used in many ways by the natives of the tropics. In fact, the palm provides almost every want except clothing. The nuts supply a large proportion of the native's food and the milky juice a nutritious and refreshing drink. The milk is especially wholesome in immature nuts, the meat of which is a delectable, rich, jelly-like dessert. The nut meat is formed by growth of the surrounding endosperm part way into the milk-filled cavity. Copra and coconut oil are the coconut palm's most important products in world trade. For local usage, the meat of the mature nut is boiled in water, the oil drawn off and used for cooking and as fuel in lamps. The oil is removed from the commercial product, however, by modern extraction methods in both production and consumption centers.

The sap of the unexpanded flower spathe may be consumed upon being drawn from the plant, or converted into syrup or sugar; or, if fermented, it may be distilled to make arrack, a potent alcoholic beverage. The flow of sap is stimulated by treating the wound with cinnamon leaf paste or lime.

Coconut shells are used by the natives for fuel, kitchen utensils, cups for drinking, buttons and other uses. Charcoal prepared from the shell is exported for use as an absorbent in gas masks. The fiber of the outer husk of the nut is known as "coir", which when retted and bundled is an important export product. From it durable and salt-resistant ropes, cordage, upholstery material and brushes are made. The common hairy doormat is made from shredded coir. The coconut palm also provides the fiber for the coconut type straw hat which is now worn extensively in the United States and probably is second in favor after the Panama or Ecuador type.

The leaves of the palm serve as roof thatching, flooring, wall fabricating and as a general matting. Leaves are plaited into fans, baskets and numerous other things. The trunk provides the natives with timber for their buildings and furniture, and with firewood. The wood of the coconut palm is known in the lumber trade as "porcupine wood". Seasoned coconut palm timber has a peculiar and attractive grain and a dark wine color; it is adaptable to ornamental carving and is exported to temperate regions.

The root of the coconut palm has no commercial value, but it is utilized by the natives. Inhabitants of southern India, for instance, brew a beverage from the tender roots, the flavor of which is similar to that of coffee. In India, Ceylon, the Malay States and other eastern coconut areas the roots are steeped, and the resultant liquid used as a medicine for various ailments. In Ceylon the roots are roasted, ground and employed as a dentifrice. They are also steeped there, and the resulting liquid is used as an antiseptic for bathing wounds, mouth-washing and gargling.

Because of its many uses locally and throughout the world, the coconut palm receives attention everywhere. In 1946 the United States imported 50 million coconuts in the shell, 17 million pounds of desiccated coconut meat, 3.3 million pounds of coconut oil cake, 800 million pounds of copra, and 2.3 million pounds of coconut oil. These quantities were somewhat below prewar levels. Except during the depression, U. S. consumption of these products has increased continually for several decades.

The fats and oils industry is one of the great industries of our country, and the coconut palm is of major concern to it. Many American engineers, economists and other specialists are engaged by U. S. firms in tropical areas to facilitate inter-

national trade in the coconut palm commodities. American ingenuity has developed new oil-crushing methods, new oil refinement techniques, new preparation methods for the edible coconut meat and new uses for many of the coconut palm products. Representatives of the Office of Foreign Agricultural Relations, United States Department of Agriculture, are sent by our Government's Foreign Service to Embassies and Consulates throughout the tropics. One of their functions is to observe and report to Washington conditions in the coconut areas. They submit data on production, export movements and other aspects of the industry, and this information is provided to the trade through foreign crops and market reports issued in Washington. U. S. technicians have also been sent by this Office into the producing areas to give advice on the processing, grading and marketing of the coconut products in an effort to improve the quality.

For the economic botanist the coconut palm is interesting because its oil competes with animal oils and oils derived from temperate-climate plants. For the economist, politician and statesman the coconut palm is interesting because its oil promotes trade warfare and tariff barriers between the tropics and temperate regions to such a degree that U. S. fat and oil producers (peanut, cotton, flax and hog growers) claim that domestic production of oil must have tariff protection, otherwise it can not compete against the tropical outturn.

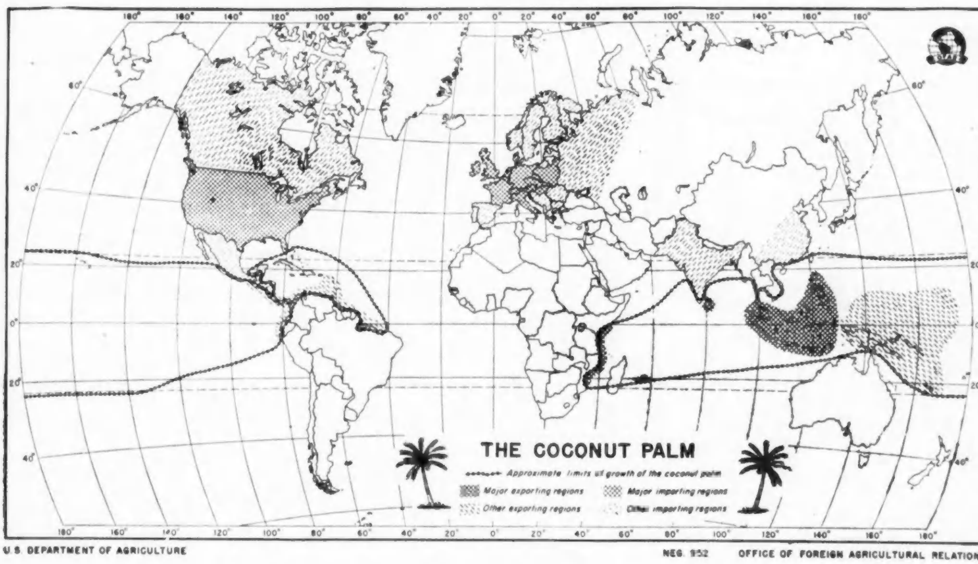

FIG. 1. The coconut palm is widely distributed throughout coastal areas of tropical and subtropical countries, generally within 20 or 25 degrees of the equator. Production is centered in the East Indies, South Asia, Pacific Islands, East Africa, Central America and the Caribbean. Consumption of the coconut and its products is heavy in North America, Europe and South Asia.

Habitat and Means of Distribution

The coconut palm is widely distributed throughout coastal areas of tropical and subtropical countries and in some places inland (Fig. 1). It grows generally no farther than 20 or 25 degrees from the equator, although there are certain exceptions, and the yield of nuts falls off appreciably in plantings more than 20 degrees from the equator. Thus com-

mercial plantings are located in a narrow belt. The plant is found throughout the American tropics in Central, Caribbean and South America, and has been introduced on a small scale in east Africa and the neighboring islands. However, in western Africa the coconut palm is seldom encountered, although the oil palm (*Elaeis guineensis* Jacq.), from which palm oil and palm kernel oil are obtained, grows widely there.

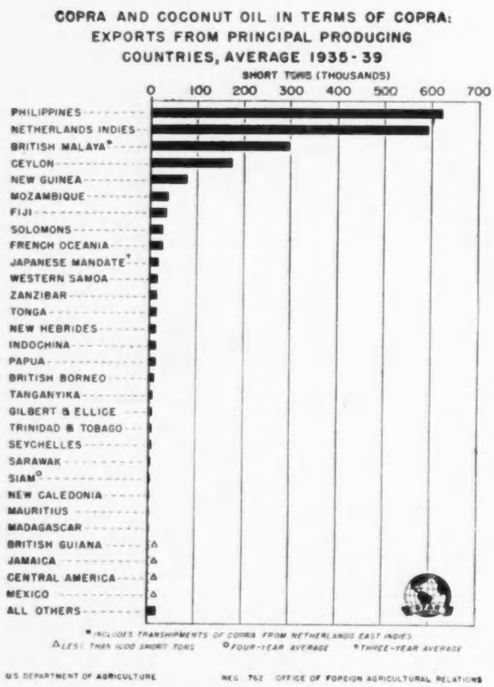

FIG. 2. The largest exporters of copra and coconut oil are the Philippines, Netherlands East Indies, British Malaya and Ceylon. (*From "Fats and Oils World Production and Trade", Foreign Agricultural Report No. 11, p. 44, August 1946, Off. For. Agr. Rel., U. S. Dept. Agr.*).

The principal areas of commercial coconut production and export include the Philippine Islands, Oceania, the Netherlands East Indies, Ceylon and Malaya (Fig. 2). Ninety-three percent of the copra and coconut oil entering world trade during the period 1934–38 came from there. The coastal regions of India, Burma, Siam and French Indo-China are important producers but export little. India supplements its production with imports chiefly from Ceylon.

The coconut grows prolifically throughout the South Sea islands. Numbers of Polynesians, Melanesians and Micronesians, living on atolls in the equatorial belt across the Pacific, survive chiefly on the coconut palm and its products. Typically these islands consist of sand-covered coral rings which surround shallow lagoons. They support stands of windbent, grey-trunk coconut palms topped with feathery green-to-golden fronds.

Many coconuts fall upon the beaches throughout the tropics and are carried to sea by the ebb and flow of the tide. The hard-surfaced outer husk is practically water-proof and safeguards the inner nut or seed for months while it is seaborne. Mariners on the tropical seas often notice coconuts adrift. The nuts frequently are cast up on a coast, and if conditions are favorable, palm trees grow from them. Because of its adaptability to water travel in this manner, the coconut palm now encircles the earth. It has been called the "ocean-going nut" and described as a good navigator.

The coconut grows best at low altitudes near the coast where the minimum annual rainfall is about 60 inches and fairly well distributed throughout the year. Palms located inland generally bear few, if any, nuts, presumably because they seem to thrive best in a salt atmosphere. Experiments in Puerto Rico indicate that the addition of three or four pounds of salt annually to the soil about each palm may increase the yield of inland plantings.

The coconut can survive on as little as 40 inches of rainfall yearly, but it prefers much more. It can survive, moreover, through several months of drought, provided ample subsurface moisture is available. Temperatures as low as 40 to

50° F. can be withstood temporarily, but continuous temperatures of 80 to 90° F. are preferable. Commercial plantings are made in coastal areas having 60, 80 and more inches of rain evenly distributed throughout the year, high uniform temperatures and accessibility to ocean transport.

The soil moisture requirements are rather exacting. Circulating ground water is essential. Stagnant ground water is harmful and often fatal. Some of the best stands of the palm are along coasts lying adjacent to mountain ranges. This insures good water movement through the soil. Certain inland mountain valleys have similar ground water conditions and thus are suitable for the palm's growth. Some commercial plantings have been made at 1,500 feet and higher where climatic conditions are favorable, but it is infrequent that the required conditions occur at elevations much above sea level.

Since good soil drainage is a prerequisite, clay soils or subsoils are unsuitable. Any locality where the water table is near the surface of the soil is not suited to the palm. However, it is not exacting as to soil composition and is found growing in about every kind of soil except clay. Soils of volcanic origin, coastal sand and deep alluvial deposits are especially well adapted to the coconut palm's growth. Open sunny country is required, and cloudy weather is detrimental because photosynthesis must proceed at an active rate.

American Tropics[2]

Coconut palms grow along the tropical coasts throughout Latin America. The palm grows along the Pacific-facing coast from the State of Nayarit in western Mexico southward along the Central and South American coast to Ecuador. It grows along the Central American Gulf coast from the State of Veracruz in Mexico down through Panama, thence around the Caribbean and Atlantic-facing South American coast through the State of Baía in Brazil. It grows on most of the islands throughout the Caribbean and appears in especially large numbers in Trinidad, Tobago and other of the Lesser Antilles islands.

About a million acres of bearing coconut palms grow throughout the American tropics. Plantation culture of the coconut palm is practiced in limited regions in the Americas, and it has not progressed to the extent found in the tropics of the Far East. In comparison with Asiatic producing regions, the yield of coconuts in the American tropics is low, averaging annually about 30 nuts per tree. In the Caribbean, production is curtailed by the prevalence of bud rot, scale insects and nematodes. Trade in coconut products in Latin American countries was of small value prior to World War II. The war, however, cut off Far Eastern supplies and caused the development of rather heavy American trade.

Mexico and Central America

Mexico is the most important producer of coconuts in the Western Hemisphere. It also imports large quantities of copra, 73,000 tons in 1940, chiefly from the Far East. Copra production increased from 18,500 tons in 1939 to an estimated 40,000 tons in 1945 and probably will continue to increase at a slow rate for a few years. Important producing States on the Pacific Coast are Colima and Guerrero, and on the Gulf Coast, Campeche and Tabasco.

In 1940 Mexico had 34,000 acres in commercial coconut plantings on which

[2] Production statistics in this and subsequent country and regional sections were derived from: Rossiter, Fred J., Regina H. Boyle, Douglas M. Crawford, Dale E. Farringer and Helen Francis, "Fats and oils world production and trade", Foreign Agricultural Report No. 11, Aug. 1946, Office of Foreign Agricultural Relations, U.S.D.A., Washington, D. C.

stood 2.1 million palms. In that year this area produced 53 million pounds of copra, or 1,560 pounds per acre, valued at 1.2 million dollars.

Coconuts are gathered along both coasts in Guatemala without cultivation as is common throughout Latin America. The nuts are gathered by the natives and used in various ways by the local population. Coconut products are not an important item in the commerce of Guatemala, however.

Coconuts constitute the chief export of the picturesque Bay Islands which lie off the north Caribbean coast of Honduras. Some 10 million coconuts are gathered yearly on these islands. Most of them are exported to the United States. Production also centers on the mainland at La Ceiba, but the outturn is less here than on the islands.

Nicaragua exports about 1.5 million coconuts yearly. Production has increased substantially in the last few years. One company has planted some 60,000 trees, and natural stands occur along the entire 360-mile Caribbean coast. A heavy natural stand of coconut palms is found on the Corn Islands off the Caribbean coast. Much Nicaraguan copra comes from these islands. Most of the output is used in the domestic manufacture of soaps, cooking oil and shortening.

The coconut thrives in natural stands on the Pacific and Atlantic coasts of Costa Rica. Along both coasts of Central America and the offshore islands, coconut schooners sail from place to place collecting and buying nuts from the natives. After collecting a load they sail to the major ports and discharge their cargo for domestic usage or export.

Some of the finest coconuts in the world are produced by the San Blas Indians who inhabit the 300-odd Caribbean islands lying off the 120 mile-long San Blas coast of Panama east of the Panama Canal. Coconuts are the chief source of income for these Indians who travel throughout the islands in dugout canoes and collect the nuts from natural stands of the palm. Systematic plantings have been made along the coast. The yield from the latter is high, and the nuts are of outstanding quality. Coconuts are used for currency and are valued at about a cent each. The output of copra and fresh nuts is carried by canoe and sail boat to Colon where it is exported, mostly to the United States. The San Blas Indians are noted for their ability to drive a hard bargain in making their sales.

Coconuts are produced in substantial quantities in Panama also off the Caribbean coast at Bocas del Toro and along the Pacific coast at the Gulf of Montijo. A number of plantations were established in these areas early in the century but were later abandoned. High prices during and after World War II stimulated new interest in them, however. About 2,500 tons of copra were produced in Panama in 1945.

Caribbean Islands

Many islands in the Caribbean are suited to the production of coconuts, and cultivation of the palm has become important on a number of them (Fig. 3). Trinidad and Tobago of the British West Indies, located in the Caribbean north of the eastern coast of Venezuela, are the second most important Western Hemisphere producers, after Mexico. Several thousand acres have been planted in Trinidad which are producing between 50 and 75 million nuts yearly. Scientific culture is practiced on a number of coconut estates, and considerable research has been undertaken at the Imperial College of Tropical Agriculture in Trinidad. The British in Trinidad have utilized the experience gained in the East Indies where coconut growing is practiced on a large scale. About 12,000 tons of copra are produced annually in Trinidad and Tobago.

Jamaica, which lies in the Caribbean south of Cuba, normally harvests about 90 million coconuts annually and produces some 8,000 or 9,000 tons of copra.

Puerto Rico, Haiti, Dominican Republic and Cuba are minor producers, with only a few commercial plantings.

FIG. 3. Coconut palms grow along the tropical coasts throughout Latin America. This scene is typical of the Caribbean. (*Courtesy Pan American Union.*).

Throughout the Caribbean region the coconut palm frequently is injured by hurricane winds.

Florida

The coconut palm has been planted along the Atlantic coast of Florida from Palm Beach southward to, and somewhat below, Miami, but only a few plantings have been made for the production of nuts. The palm grows satisfactorily but the yield of nuts is small. During World War I our Government was interested in coconut production in Florida as a source of charcoal for gas masks. During World War II growers harvested the nuts and prepared grated coconut for the confectionery and baker's trade and home use. The product was rather crude because it was prepared without the proper machinery.

South America

Coconuts grow in northern South America along certain coastal areas in Ecuador, Colombia, Venezuela, British Guiana, Surinam, French Guiana and as far south in Brazil as the State of Baía. In Ecuador the coconut palm grows in the seaboard Provinces of Manabí and Esmeraldas north of Guayaquil. Four processing plants, all located in Manabí Province, produce copra and coconut oil, practically all of which is used domestically because the total output is generally less than the quantity required by soap manufacturers. From 300 to 360 tons of coconut oil are produced annually which is a relatively small output.

Ecuadoran coconut production has been reduced as much as 60 percent in the last few years by devastating attacks of a worm which, according to the Ecuadoran Department of Agriculture, is known as *Richophorum*. No remedial measures have been taken other than the planting of more palms.

The coconut palm flourishes from Guayaquil inland to the mountains. Since the lowlands between the sea and the Andean foot-hills is broad along most of the Ecuadoran littoral, a large area could be planted to it.

In Colombia coconuts are produced along the Caribbean coast near Barranquilla, on the San Andres Islands and inland in the Department of Magdalena. Most of the land suited to coconut culture is unexploited. Nevertheless, Colombia imports about two-thirds of the copra it needs.

Some five to six million coconut palms are in Brazil, mainly along the Atlantic coast in the States of Sergipe and Baía. The output is consumed locally. In 1944 coconut oil production was reported at 3,000 tons, or more than double

the 1930–39 average. Coconut production could be increased many-fold in Brazil, since the palm can grow for a considerable distance up the Amazon and along the coastal plain from this river's mouth south to Santos in the State of São Paulo. Only two or three scientific plantings have been made in Brazil, however.

To summarize, the coconut palm grows throughout the American tropics, but, with the exception of a few areas, commercial culture is not practiced. The natives do not depend upon it for sustenance to the extent followed in the South Pacific and Far East, and its various products are not utilized to the same high degree.

Commercial Coconut Areas

The principal areas of commercial coconut production embrace the Netherlands East Indies, the Philippines, Ceylon, India, Malaya and Oceania. The Netherlands East Indies is the leading producer but ranks second to the Philippines in exports because the Indies population consumes a considerable portion of the outturn. The Philippines hold second place in production and India third. Domestic consumption is heavy in India, however, and imports are required.

All of the principal coconut exporters except Ceylon are included if a circle is drawn about Manila on a 2,500 mile radius (Fig. 4). Within this circle exists almost one-third of the world's population, and from it come about 90 percent of the world's natural rubber, 70 percent of its tin, 65 percent of the rice, 60 percent of the tungsten, 55 percent of the copra, and over 10 percent of the cotton[3]. In the densely populated Netherlands East Indies, Philippines and Ceylon, rice is the leading crop because it is needed as food, but the acreage devoted to it is encroached upon by the production of export crops of which coconuts and sugarcane are most important. In Java the Dutch Government has placed restrictions on the cultivation of commercial crops for export

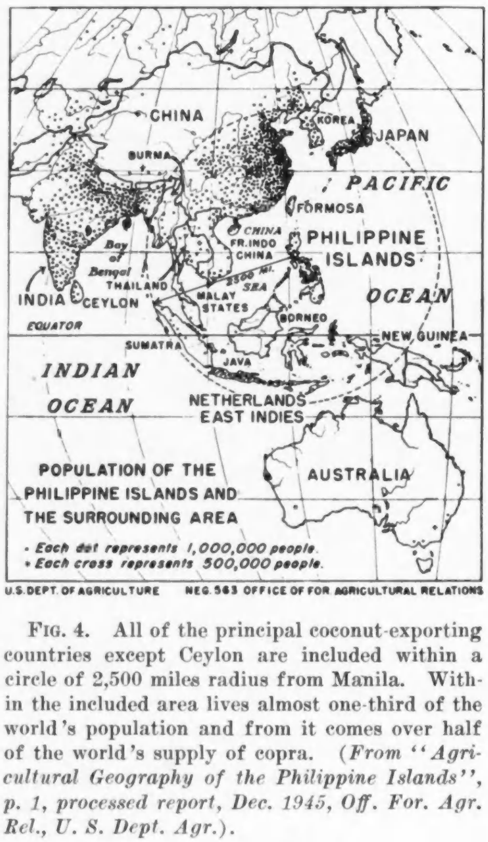

FIG. 4. All of the principal coconut-exporting countries except Ceylon are included within a circle of 2,500 miles radius from Manila. Within the included area lives almost one-third of the world's population and from it comes over half of the world's supply of copra. (*From "Agricultural Geography of the Philippine Islands", p. 1, processed report, Dec. 1945, Off. For. Agr. Rel., U. S. Dept. Agr.*).

to insure the production of adequate food. Thus within the encircled area copra is exceeded by only one other food crop, rice.

Philippine Islands

In 1938 there were approximately 140 million coconut palms on 2.6 million acres in the Philippines. Sixty percent of these palms were bearing. The fol-

[3] Hainsworth, Reginald G. and Raymond T. Moyer, "Agricultural geography of the Philippine Islands", processed report, Office of Foreign Agricultural Relations, United States Department of Agriculture, Washington, D. C., December 1945.

lowing year 2.3 billion coconuts were produced. Exports averaged 336,000 tons of copra and 180,000 tons of coconut oil yearly, 1935–39. Copra production in 1947 is estimated at 850,000 tons which is substantially above the 1934–38 average annual output of 650,000 tons. It is estimated that one-third of the Philippine's population of 18 million depend upon the coconut industry for a living.

As a result of the Japanese occupation, all facilities for harvesting, copra making, oil expelling and marketing were destroyed, demanding reconstruction of the industry after the surrender of the Japanese. Crushing facilities slowly are being reconstructed at Manila and Cebu, the major outlets for exports.

Imports of Philippine coconut oil and copra into the United States are duty-free. After 1954 duty must be paid on increasing quantities of coconut oil imported into the United States, however, while copra will continue to enter duty free. This probably will lead to more oil extraction in the United States. The Philippines have been the United States' chief source of coconut oil and copra.

Coconuts are grown on about 27 percent of the total cultivated area in the islands. A larger area is in rice which is the only crop exceeding coconuts. In some areas over 50 percent of the cultivated acreage is in coconuts. The coconut palm is found along the sandy seashore of all the Philippine Islands except in northern Luzon where its growth is restricted by devastating typhoons in the east and a long dry season in the west. In the interior valleys and plains and on steep terraced slopes, rice is raised for food and sugar and tobacco for export. Abacá, or Manila hemp (*Musa textilis* Née.), is grown for export along the east and southeast coasts of Luzon below the typhoon belt.

Although most of the Philippine coconuts are produced on the seashore, one of the world's largest coconut regions and the heaviest planted area in the Philippines is inland at the base of Mount Banchao, an extinct volcano in southern Luzon. Good ground water circulation is found at its base because rain water moves through the porous rich volcanic soil, picks up plant nutrients and flows down to the lower levels where it is available to the roots of the palms. Other centers of production are on Samar on the Pacific or eastern side of the Philippines archipelago; on Cebu, Bohol, and Leyte in the center of it; and in northern Mindanao, the large southern island.

Coconut production in the Philippines expanded rapidly after 1916. Expansion occurred much earlier in Ceylon and the Netherlands East Indies. Demand for coconut oil for food uses began in Europe in the middle 1800's, but United States demand did not develop until World War I. Thus Philippine output on a commercial scale got a comparatively late start, but coconut, copra and coconut oil outturn increased on a phenomenal scale with American and British capital and management.

Since 1921 U. S. imports of Philippine crude coconut oil have had a 2 cents a pound duty preference. This gradually will be eliminated after 1954, as mentioned above. Most European coconut oil-importing countries except Great Britain and Sweden have maintained high duties on coconut oil imports but not on copra, to promote manufacturing at home. The Philippines is the only producer that has been able to export both oil and copra in volume.

However, local extraction of the oil is hindered by the small local demand for the residual product—coconut cake—the value of which does not justify its transport to the U. S. Interest rates, overhead and selling charges are higher in the Philippines than in the U. S. Even with the tariff preference, com-

petition is keen with Philippine and U. S. crushers. Thus the Philippines may not remain in the crushing business after 1954.

Pacific Islands

The southwest Pacific islands, or Oceania, are important producers of copra. This is the major and often the only commercial product of most of these islands which are of volcanic and coral origin. The coconut provides the chief food of the island inhabitants. A number of tropical plants have undergone experimentation on many of these islands, but with the exception of certain of the Fiji and new Hebrides islands, none has proved successful, because of either labor scarcity or unsuitable climate. The coconut palm, consequently, is the only commercial plant throughout a large area in the southwest Pacific.

From 1935 to 1939, this area (excluding the Philippines which is discussed independently) produced about 242,000 tons of copra annually, representing about 13 percent of the annual world trade in this commodity. Because of improper drying, the copra produced in these islands is of poor quality, frequently moldy and sells at a low price. Because of heavy and continuous rainfall in many areas, sun-curing is difficult and mold results. The use of drying kilns is increasing, and the quality of the output improving.

The islands in this grouping, named in order of importance as copra exporters, include: New Guinea, Fiji, Solomon Islands, French Oceania (including Tahiti), Western Samoa, Tonga, New Hebrides, Papua, Gilbert, Ellice, Marianas, Caroline and Marshall Islands, and New Caledonia. Many of these are under either British or French control.

Most of the production is from native-managed groves, but in the British islands a number of large British-managed plantations are to be found in the more heavily populated regions. Large scale production has been prevented in many areas because of scarcity of inhabitants and the near-savage state of many. Rainfall varies from 100 to 150 inches annually on many of the islands, but on others it is about 75. The temperature is high with little seasonal variation. Most of the islands consist of coral reefs and sand.

The Territory of New Guinea under Australian mandate is the most important producer. The annual copra output during 1935–39 was a little in excess of 77,000 tons, and the area in the coconut palm in 1940, 265,000 acres. Most of the Territory's output is shipped from the port of Rabaul on the island of New Britain. A large area is suitable for additional plantings. The Japanese occupation seriously harmed the coconut plantings, but rapid recovery has been made.

The British Crown Colony of Fiji is the second most important in this grouping. The islands consist of the summits of extinct volcanoes. They have rich soil and humid climate and are well adapted to plantation farming. Only a few of the 250 islands in the Colony are important coconut producers. In 1935–39 Fiji exports averaged 34,000 tons annually. Some 63,000 acres of the coconut palm were reported in the Solomon Islands in 1940, chiefly on Ysabel, New Georgia and Guadalcanal. The yield per acre is very high. In the Gilbert and Ellice Islands 20,000 acres are reported under native-management and none under foreign operation. Foreign-owned plantations are located on Christmas, Washington and Fanning Islands in the Caroline group.

From the Tonga islands 13,000 tons of copra were exported annually during prewar years from native-managed wild stands. An estimated 45,000 acres of the palm in the Territory of Papua in New Guinea yielded some 14,000 tons of

copra for export yearly in 1935–39. The islands (Society Islands and others) in the French Oceania group shipped 24,000 tons annually in 1935–39. The Marianas, Carolines and Marshalls—under Japanese mandate prior to World War II—shipped some 16,000 tons annually from commercial plantings during the same period.

From the British and French condominium in the New Hebrides about 25,000 tons of copra are exported annually which is produced on small native plantings. In the New Hebrides and Fiji Islands, rice, sugar, cocoa, coffee, sandalwood, cotton and coconuts are produced, while in most of the other islands coconuts constitute the only cash crop.

Netherlands East Indies

Coconuts are produced throughout the islands in the Netherlands East Indies for food and export. The major islands in this group are Java, Bali, Sumatra, Borneo, Celebes and Netherlands New Guinea. An average of 600,000 tons of copra and coconut oil in terms of copra were exported annually during 1935–39. Coconut oil constitutes only a small part of total exports. Production is mainly in the hands of natives. However, there are some European owned and managed coconut estates that generally average about 200 acres in size in Java, Sumatra and Borneo. There are no reliable estimates of the number of coconut palms in these islands nor of the yield of coconuts, but the Netherlands East Indies are considered the world's largest coconut producer.

These islands lie astride the equator and have a hot and humid climate. They receive heavy rainfall, especially from October to March when the northwest monsoon prevails. However, they never experience a dry season, although the southern coasts are somewhat drier than the northern ones because of the prevalence of southerly winds which come from the Australian deserts. The soils, volcanic in origin, are authoritatively said to be the world's richest.

A number of Javanese crops exceed the coconut in importance. Rice, corn and cassava are the principal foodcrops, and the Dutch Government has attempted to insure adequate production to feed the 42-million-odd inhabitants of the island. The population density of 818 persons per square mile is one of the highest in the world. Sweet potatoes, peanuts and soybeans are secondary foodcrops. Large areas are devoted to sugar, rubber, tea and coffee which are produced under estate cultivation, while the foodcrops are cultivated in small plantings by natives. A large part of the coconut acreage is interplanted with kapok. Most of the coconuts grown on Java are used domestically. There are 37 oil-crushing plants that produce oil, mainly for local use. Most of the Indies copra exports come from islands other than Java, although some is carried to Javanese ports for export.

In Java, Sumatra and Bali coconut palms are generally planted in dikes between fields of irrigated rice. Thus coconuts are raised all over the islands wherever rice is grown, whereas in the Philippines compact plantings of coconuts are found. In the latter the byproducts of the palm and nut are not utilized, but in the Netherlands East Indies coir fiber is made from the husk, and the shell, fallen leaves and stems are used for fuel.

Sumatra's crops and climate are similar to Java's. Its population and crops output are smaller, although it is much larger in size. Land is more readily available and thus expansion more likely. The population is increasing because of immigration of Javanese, Chinese and others. Large plantations have been established for the production of coconuts, rubber, palm oil, tobacco and coffee.

Borneo is divided into two regions.

British North Borneo and Dutch Borneo. This island exceeds the British Isles in size. Development has been restricted to scattered areas along the coast with the most extensive in the British region. Crops similar to those of the lowlands of Java are produced under plantation management. Petroleum resources have led to heavy exploitation in Java, Sumatra and Borneo.

The Netherlands East Indies have not made as rapid a comeback in copra and coconut oil outturn as the Philippines. This is due to more drastic devastation by the Japanese and agitation on the part of certain natives against the Dutch.

Ceylon

This British island is about the size of Maryland and lies off the south Indian coast. Its coconut industry is more highly developed and efficient than any other. Half of the island's exports consist of tea, a quarter of rubber and a quarter of coconut products, most of which are produced on large plantations. The humid interior south-central valleys and high land produce tea and rubber. The coastal plains, especially those of the south and west, produce coconuts, rice, mangoes, breadfruit and spices. Since Ceylon was not occupied by the enemy during World War II, it served as the chief source of coconut oil during the war years for the United Nations, and its output of coconut products was maintained. Its copra is of the highest quality, and coir fiber is utilized to a greater extent than elsewhere.

The success of the Ceylonese coconut industry is due in part to two governmental agencies, the Ceylon Coconut Board and the Coconut Research Scheme. The Coconut Board assists in maintaining the quality of the products and in advertising, grading and marketing the output. The Research Scheme is an experimental station employing scientists who attempt to improve the quantity and quality of the output through genetic, pathological, entomological and grove management research.

The first commercial Ceylonese plantings were made about 1840, and the acreage steadily increased thereafter. There are about 1.1 million acres in the coconut palm today, representing perhaps one-seventh of the total world area in commercial coconut production. The yield fluctuated between 2.0 and 2.2 billion coconuts per year during the 1930's, but has decreased somewhat in the 1940's because of a reduction in the application of fertilizer. Annual exports of coconut oil and copra averaged 170,000 tons during 1935–39.

The coconut palms are rather carefully cultivated. Plowing is done in many areas with elephants. Green manure is commonly grown and turned under, and potash applications have been found to increase the yield as much as 20 percent.

The husk in Ceylon is widely used for making coir fiber. It is retted and the fiber is extracted from it by machine or hand. Two grades of fiber are made, mattress and bristle. The bristle is used for making doormats and brushes; the mattress for cushions, carpets and upholstery materials. Some of the mattress fiber is spun into yarns from which carpets, rugs and various fabrics are woven by hand and on looms.

India

Coconuts are grown along much of the coast of India and as far inland as a hundred miles. The country is estimated to have approximately 1.5 million acres in the palm. Of this, 1.2 million acres are located in British and Native Madras which include the Malabar and Cochin districts. Other important producing regions are in the Bombay presidency, Lower Burma, Bihar and Orissa. Mysore is another important native state that produces coconuts. Rainfall

on the Malabar coast frequently reaches 150 inches yearly, but on the east Madras coast and in Mysore it is less than 50 inches. India's coast is wet from June to September and dry the rest of the year, but the coconut palm thrives, nevertheless.

A few companies based in London operate coconut plantations in combination with tea. Most Indian coconut, however, is produced on small and efficient native tracts. The great Indian population consumes the entire output as fresh coconut and coconut oil. There are many small, crude mills that express the oil. The Indian populace consumes large quantities of vegetable oil.

Malay Peninsula

The European plantation system is well established on the Malay Peninsula where some 40-odd companies incorporated in London operate coconut plantations. Many of the coconut plantings are in combination with rubber. The rubber acreage is about six times as great as the coconut (620,000 acres estimated for 1940), but the latter is the second most important industry. Rice is an important food crop, but large quantities must be imported. The largest coconut acreage is in the Unfederated Malay States (290,000 acres in 1940, chiefly in Johore), followed by the Federated Malay States (250,000 acres, chiefly in Perak and Sellanger) and the Straits Settlements (75,000 acres). Production of copra on the entire Malay Peninsula was estimated at 225,000 tons yearly during 1935–39.

The quality of copra produced on the Malay Peninsula is poorer than that of India and Ceylon but better than Oceania's. Sun-curing is supplemented with fire-curing in the wet season.

Africa

Coconuts grow on a fairly large scale on the coast of eastern Africa but only to a slight extent on the west coast. The most important east coast producer is Mozambique in Portuguese East Africa. It had 142,000 acres in the palm in 1941, and the yield is about 155 million coconuts per year. Copra production averaged 42,000 tons yearly in 1935–39, and most of this was exported. Since then production has increased somewhat.

In the British East African holding of Kenya, Territory of Tanganyika, and Zanzibar commercial copra output is about 30,000 tons yearly. On Madagascar, which lies in the Indian Ocean to the east of the African coast, production of copra increased from 2,500 tons in prewar years to 4,200 tons in 1945.

Biology of the Coconut Palm

The Tree. The coconut palm generally grows to a height of 60 to 100 feet, and its cylindrical stem may attain a diameter of two feet. In Ceylon a coconut palm 117 feet in height has been recorded. The palm terminates in a crown of long graceful pinnate leaves which at first are bright green, but which upon aging turn golden, and upon dying, a bamboo tan. Green leaves are at the top of the crown, golden edged ones in the center of it, and tan ones hang at the bottom. The coconut palm is a monocotyledon, and as such forms only one vegetative bud during its life from which the leaves develop. If the bud is removed or extensively injured, the tree dies.

Under average conditions the tree starts bearing at seven years of age and reaches its full bearing potential at about 10 years; under some conditions bearing may start at five years or as late as 15[4].

The Root System. The coconut palm, like other monocotyledons, forms no tap root. It produces throughout life uniformly sized roots of three-

[4] Snodgrass, Katharine. Copra and Coconut Oil. 1928.

eighths to half an inch in diameter from the basal 18 to 24 inches of the stem. The number of roots per mature plant may vary from 1,500 to perhaps 7,000. Under some conditions the main roots branch, and, as a rule, they form many short-lived feeding roots which branch again and again and thus provide a large absorptive surface. There are not any root hairs.

There is marked variation in the direction taken by the roots. In some plants they tend to grow vertically; in others horizontally, depending upon the depth of the groundwater and the presence or absence of a hardpan. The root system in mature trees frequently extends for a distance of 25 feet from all sides of the stem. The roots are woody but elastic, rigid and strong, a combination which enables the palm to withstand rather severe tropical winds.

The hypodermis of the completely developed root is composed of cells having such thick, hard walls that water cannot pass through them. Therefore, water can enter only between the root cap and the point behind it where the walls thicken, usually a distance of only two or three inches. Because of this root structure salt sea water does the coconut palm no harm when a storm forces the sea inland over the beach, while an ordinary tree would be killed by it.

The Stem. Unlike dicotyledonous trees, the coconut palm has specialized strands of cells, rather than layers, through which the sap flows up and down. These are distributed throughout the entire stem. There is no cambium layer, hence damaged tissue is never repaired. And branches are not produced in the leaf axils, as in dicotyledons.

The vegetative bud from which the leaves grow is located at the apex of the stem. The stem is scarred at fairly uniform intervals, each scar representing the former place of attachment of a leaf which has lived its life cycle, died and fallen to the ground.

Wherever there are prevailing winds, as along the seashore where the wind generally blows inland, the palm leans toward the wind; along the edge of plantings it inclines toward the light.

The Crown. The leaves and upper end of the stem with its vegetative bud, or growing point, comprise the crown. The vegetative bud, commonly called the "cabbage", consists of several folded leaves in the embryonic state protected by fibrous sheaths of older leaves known as the "leaf-sheath". The bud is soft, brittle and flavorful, being considered a delicacy as a salad dish. It frequently is cut for this purpose, and the palm is not seriously harmed thereby unless too much of the bud is removed. The bud is subject to devastating attacks by the rhinoceros beetle, the red coconut weevil and bud rot disease which destroy many palms.

The vegetative bud grows rapidly, laying down new leaves. Leaf development is retarded during rainy, cloudy weather, and leaves fall more frequently in periods of rain because moist atmosphere favors the growth of tropical fungi on them. When many coconuts are ripening at one time, leaf production declines, since the growth of the fruit puts a drain on the nutrient supply. About 14 leaves on a tree will have fruit clusters in their axils, six or eight will remain on the palm after the fruit has been harvested, and the remaining 10 or 12 will be young growing leaves too young to have flowers in their axils[5].

The highest yield of coconuts comes from palms having the most leaves and the most compact crowns. A compact crown indicates that the internodal spaces are short and that the plant has formed much fruit. Seed coconuts, for use in setting out nurseries, are saved from palms having these characteristics.

[5] Sampson, H. C. The coconut palm. 1923.




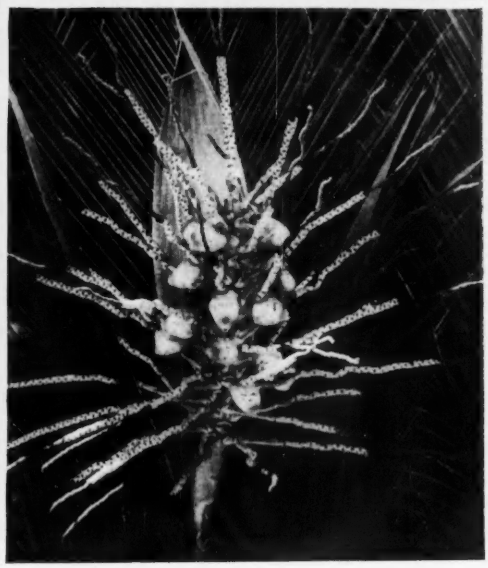

FIG. 5 (*Upper left*). An unopened spathe, one of which is produced every 26 days in the axil of each new leaf on the average bearing coconut palm. Within the spathe at this stage is an immature flowering branch, or inflorescence.

FIG. 6 (*Upper right*). An inflorescence emerged from it burst spathe. A globular female, or pistillate, flower is located at the base of most of the spikelets, or branches, of the flowering stalk.

FIG. 7 (*Lower right*). Young coconuts sometime after the female flowers have been cross pollinated and the male, or staminate, flowers have fallen from the spikelets.

FIG. 8 (*Lower left*). Three-months old coconuts which will ripen in nine more months. (*Photos courtesy Philippine Refining Corp., New York.*).

The progeny of heavy yielding palms is likely to yield heavily likewise.

The Leaf. The mature leaf, frequently 20 feet in length, is composed of a strong leaf stalk, or petiole, and a mid-rib, or rachis, to which numerous long leaflets are attached. The leaf stalk must support the leaf, which frequently weighs 25 pounds, and the bunch of coconuts which grows in the leaf axil and weighs from 30 to 50 pounds. The wide base of the leaf stalk reaching nearly half way around the stem at its point of attachment assists the petiole in carrying the combined weight of the leaf and fruit cluster. The stipules of the leaf stalk encircle the entire stem so that the leaf scar surrounds it.

Because of its location, each leaf receives a maximum amount of sunlight, the system of leaf arrangement being a two-fifths phyllotaxy. This means that each new leaf is at an angle of about 144 degrees around the stem from the last one. Hardly any leaf stalks overlap, accordingly. If a palm carries 30 leaves, they will encircle the stem about 11.6 times ($144 \times 29 \div 360$). On some palms the leaves spiral about the stem to the left and on others to the right.

The leaflets near the base of the leaf are about 30 inches long and half an inch wide; those in the center, 40 to 50 inches long and one and a half to two and a half inches wide; those near the apex 18 inches long and one-quarter to one-half inch wide.

Flowering. A flowering branch, or inflorescence, bearing both male and female flowers, is produced in the axil of each leaf on a mature tree. This flowering branch is enclosed in a spathe which splits and thereby exposes the branch when the male flowers on it are about ready to open (Fig. 5). The inflorescence is composed of a main stem eventually five to six feet in length which bears some 40 secondary branches, or spikelets; the latter in turn bear the flowers. Generally one female flower is located near the base of each spikelet, and large numbers of male flowers are borne between the female flower and the tip of the spikelet (Fig. 6). Sampson[5] has observed that the total number of male flowers on each spikelet ranges from 250 to 300, and that the female flowers number only from 20 to 40 on one entire inflorescence.

When an inflorescence bursts from the spathe, flowering starts on the spikelets at the terminal end of the flowering branch and progresses towards its base. About 15 days are required for all the male flowers to open and die. After they die and fall, the female flowers open. There are no two branches flowering at the same time on one palm. Thus, male and female flowers never open simultaneously on one tree. This necessitates cross-pollination, and the tree providing pollen may not carry the potentialities for heavy coconut production. This can be determined only by controlled breeding. Cross-pollination is assisted by insects, attracted by the honey produced by the three honey glands of each female flower.

Because of this cross-pollination there is considerable variation in the progeny from one tree and even from one bunch of nuts. Many so-called varieties of coconut are recognized in which the coating of the husk may be green, yellow, brown-green or brown-red. A few varieties breed true to type because they bear so rapidly that the flowering period of two flowering branches on one tree overlap, permitting simultaneous opening of the female flowers of one branch and of the male flower of the other. These fast-bearing types accumulate very little "meat" in the nut and hence have no commercial value.

Fruiting. Coconuts may be harvested throughout the year, since the nuts reach maturity at different times. The greatest number of fruits per tree occurs in the

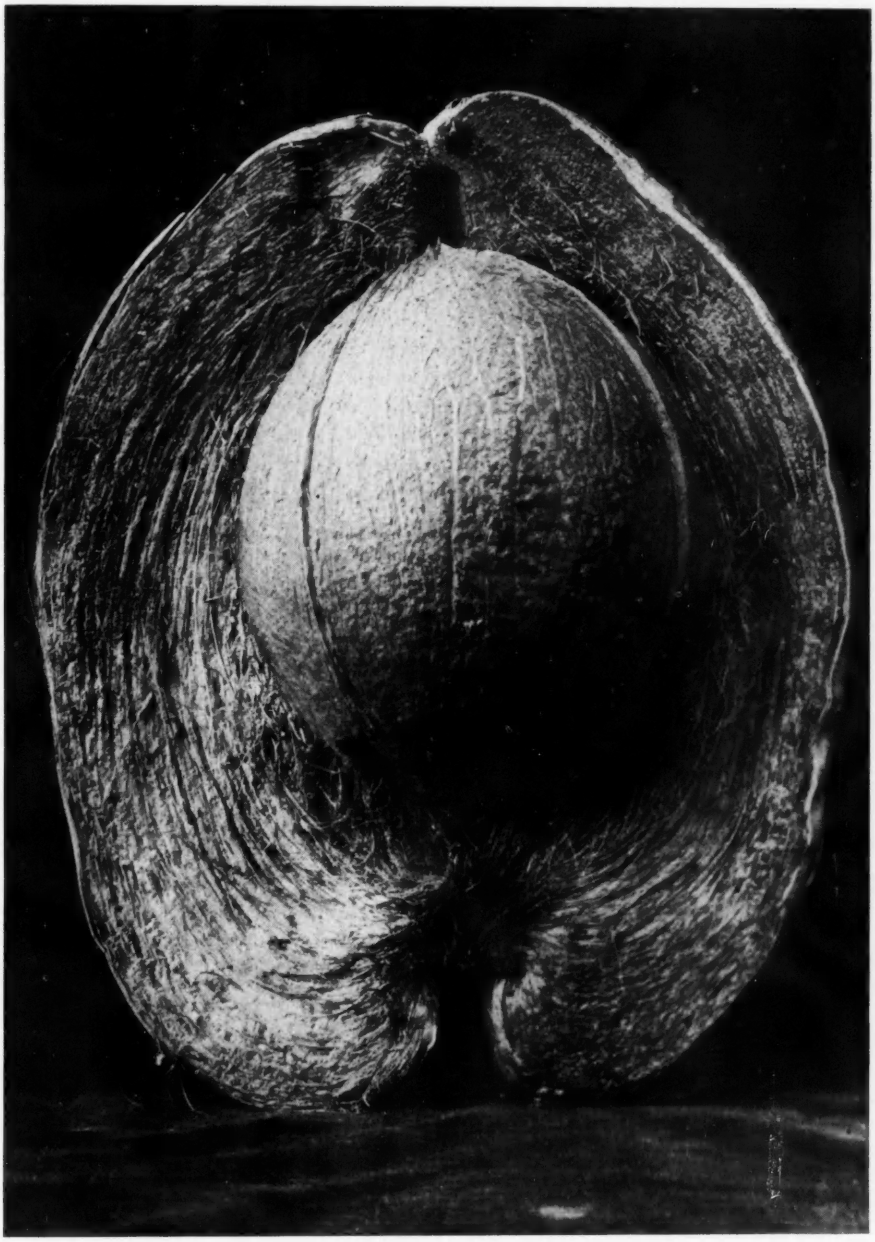

FIG. 9. The thick fibrous husk, or mesocarp, of this coconut fruit has been cut in half, but the imbedded seed, within the hard endocarp, has been left intact. The mesocarp is surrounded by a thin smooth exocarp which in the immature fruit is green. The seed, within the hard endocarp, consists of a thin testa and thick meaty endosperm surrounding the milk-filled cavity. The entire fruit consists of three fused single-ovule carpels, as is indicated by the three-sidedness of the entire fruit, by the three ridges on the endocarp and by the three germinal pores in the latter. Only one of the ovules and carpels develops; the others abort. Only the pore of the developed carpel is soft and leads to the cavity within; through it the embryo emerges as it develops into a seedling. This specimen is standing on what was its point of attachment in the fruit cluster. (*Courtesy New York Botanical Garden.*).

East Indies in May, June and July when the maximum number of female flowers is pollinated; the fewest in November, December and January. Fruit is set every 26 days, the interval at which new leaves are laid down on the average palm.

The nut requires a year to ripen. The meat starts to form at about the sixth month, and oil accumulates in the cells as the nut approaches maturity. The cavity of the kernel is filled with milk during immaturity but only partly filled with it at maturity. The meat is the endosperm, a cellular structure that grows. It is not a product of coagulation, as is often stated. The meat is completely formed by the tenth month, but the shell does not fully harden until the twelfth month.

FIG 10. A coconut removed from its fibrous husk and showing its three germinal pores and three ridges which represent the three fused carpels that compose it. (*Courtesy New York Botanical Garden.*).

The coconut is a fibrous drupe. A smooth outer skin covers the thick fibrous husk which encases the stone or nut. The nut consists of a shell, a seed coat or testa (located between the shell and the meat), flesh oil-bearing meat and liquid milk. The nut is formed by the fusion of three carpels which are represented by three ridges on its surface. Only one of the fused carpels develops into the mature coconut but each of them is represented by an "eye" at the proximal, or stem, end of the nut. Two of these eyes are hard, smaller than the third, and represent the two undeveloped carpels. Under the larger and soft eye, which connects with the milk-containing cavity of the nut, there is an embryo. Upon germination of the nut a young seedling grows from this embryo by sending a leaf-bearing stem through the husk. Roots grow from the base of the germinating plant downward around the nut's shell, ramifying through the husk and finally emerging through it to grow down into the soil. The roots obtain food from the husk and later from the soil. The germinating plant also forms a growth inside the cavity of the nut which transforms the meat and milk into sugars for its nourishment. This is the "nursing-foot" of the embryo which eventually fills the cavity and provides the growing plant nourishment for three or four months or until its root system becomes established in the soil.

Coconut Plantation Management

Management of a coconut plantation varies widely from region to region and according to the size of operation. Thus it is difficult to write in generalities. The management of an owned or rented planting operated by a small tropical grower differs greatly from one of the large commercial plantings owned by a corporation in Europe or the United States with European or American management and native laborers.

Most coconuts are produced by several million small native tropical planters whose bamboo-framed and palm-thatched houses are surrounded by a few hundred or thousand coconut palms. The nuts are harvested month by month by the planter's family, and the enterprise is

FIG. 11 (*Upper*). Husked coconuts being split with a heavy knife for production of copra. After four to six days of sun-drying, the partly dried meat is removed from the shell halves with sharp spoons, and the meat is dried further. (*Courtesy Philippine Refining Corp., New York.*).

FIG. 12 (*Lower*). Coconut nursery, showing three stages of development. In the foreground are recently planted coconuts, to the left are sprouted coconuts, and in the background are young palms ready for transplanting. (*Courtesy Agriculture in the Americas.*).

one of family size. The full time of the family is devoted to the production of the nut. Since a palm will bear for 50, 60 or perhaps 70 years, a family may work the same palms for several generations.

A commercial plantation generally consists of several hundred acres. Laborers are recruited in the vicinity and given quarters on the plantation. The local government frequently ordains the conditions under which the laborers are employed and cared for. Wages are low, and the laborers often are inefficient. Except for labor, costs are high because most supplies and equipment, including considerable of the food requirements, must be imported from distant countries.

Fig. 13. Coconuts being gathered from the crown of a palm tree. (*Courtesy New York Botanical Garden.*).

Starting a Grove. Seedling palms are started from coconuts and planted in the field. A nursery frequently is used for this purpose. Seed coconuts preferably are selected from palms of good growing habits and of high yielding potentiality. The coconuts, with the husks intact, are planted in the nursery with the embryo (or stem end) uppermost or on one side (Fig. 12). In continually moist climates the nuts need not be covered with soil, but in areas subject to dry periods they should be almost covered. When the seedling palms are from four to eight months old they are removed from the nursery and set in the field. Germination alone usually requires from one to four months.

In moist climates seed nuts are sometimes tied in pairs and hung on poles or across horizontal supports of some description in place of setting in a seedbed. The pairs are placed in the shade and sprinkled with water at intervals to induce germination. The seedlings thus obtained are planted in the field when they reach a suitable size.

Plantings preferably are made on land cleared of virgin forest. The trees should be set at intervals of 25 to 35 feet, but most plantings are set closer than this so as to get the most trees on the land. The quincunx is probably the best planting system. Transplanting is practiced during the wet season, and the plants are set in holes at a depth so that the coconuts from which the seedlings are growing will be just below the ground level.

Cultivation. The coconut planting will survive if left alone, but most planters cultivate and grow catch-crops until the palms start bearing. Various crops adapted to the area can be interplanted as the catch-crop. Beans, upland rice, corn, manioc and others are common. The catch-crop serves as a source of food and cash for the planter and his family, but shading the young palms must be avoided. An area about four or five feet in diameter is kept clean around the base

of each palm. Cover-crops are frequently used to keep down grass and for turning under, thereby adding to the fertility of the soil.

In the mature grove the soil should be kept reasonably clean. Cultivation is often practiced to advantage, especially where a dry season is encountered. The soil mulch formed by cultivating retards evaporation and hence conserves soil moisture. The soil is either turned by plow or pulverized by discing. In most areas either the bullock or water buffalo is used for plowing. Fertilizing increases the yield of the nuts, and various mixtures of organic and inorganic materials are applied.

Harvesting. In harvesting, some coconuts are picked up from the ground after they have fallen from the palm. The better plan is to pick them from the plant a month or two before they fall, at which time the meat of the nut is well matured. The native harvester may climb the palm by means of stepwise notches cut in the trunk and may cut or twist the bunches off (Fig. 13); or he may remain on the ground and use a curved knife fitted to a long pole. The latter is the better method, since notches harm the tree and tree climbing is hazardous in wet weather. By use of a knife fitted to a sectionalized bamboo handle which screws together at the joints, a harvester can pick more nuts from the ground than by climbing the trees. Harvesting is done every two or three months, and two or three bunches of nuts are cut per palm. They are collected by men, women and children, and are carried to the planting's headquarters on sleds or carts drawn by water buffalo or other available beasts, to be stored in central piles for two or three months until cured (Figs. 16, 17).

Copra Production

The first step in making copra or in preparing fresh coconuts for market or shredding consists of husking the nuts. By three or four strokes of his arms a husker tears off the thick fibrous husk on a plow point fastened with the point up. A good worker can husk from one to two thousands coconuts daily.

The second step consists of native men or women opening the husked nuts by striking them at the equator with a heavy knife. This splits the nuts in half, and the milk spills out on the ground. The open halves are placed on trays and turned up to the sun. The trays can be stacked one upon another and quickly covered with a roof in the event of sudden rain. After four to six days of sunning, the partly dried meat is removed from the shell halves by prying with a sharp curved steel spoon. The meat is then further dried by sun or, if frequent rains prevent sun-drying, it is cured by the use of one of several types of driers which pass heat or heat and smoke through trays of the meat placed under a shelter. The shells and husk of the nut frequently are burned to provide the heat used in flue curing. In Ceylon and India the husk is used in making coir fiber, as mentioned previously.

After drying, the meat is termed "copra". The water content of well-cured copra is reduced from 45 or 50 percent to three, four or five percent, and the oil content increased to 60 or 65 percent. However, a large quantity of the copra marketed contains as much as 10 percent moisture. If the moisture content exceeds four percent, putrefaction is likely to occur and the oil is apt to become rancid. The dried product is chopped into rather uniformly sized pieces, sacked and weighed. The sacked copra is carried on small sailboats, or overland, to local oil mills or to seaports for export. Flu-cured copra sells at a higher price than sun-cured, being sold for oil expression and for the preparation of shredded desiccated coconut for use by the bakery and confectionery trades. Most shredded

FIG. 14. Ripening coconuts near football size. At this stage they change in color from green to dull brown, the husk dries and shrinks, the meat becomes thick and firm, the cells of the meat become laden with oil, and the shell becomes hard and protective. (*Courtesy Philippine Refining Corp., New York.*).

coconut is especially prepared for food use as described later.

Manufacture of Coconut Oil and Cake

Many of the native mills in India prepare a fine grade of coconut oil by pounding fresh coconut meat to a pulp and throwing it into boiling water, whereupon the oil rises to the surface of the water and is then skimmed off; the residual pulp is used for cattle feed. Large hydraulic presses are replacing the primitive native presses which have a small outturn of oil at comparatively high labor cost. Hydraulic installations are found in Europe, the United States, the Philippines, Java and Ceylon as well as in India. Prior to World War II the Germans extracted the oil also by use of solvents, in place of pressing, but hydraulic pressure is the important method.

Hydraulic expression comprises several processes. The copra is first reduced to a meal by revolving rollers and carried by an elevator to a kettle placed above the presses. Heating and steaming in the kettle rupture the cell walls and release the oil. The crushed, steamed copra is then delivered from the kettle to the presses below where pressure of from three to four tons per square inch squeezes the oil from the solid portion of the material. The crude oil drains off and the residue is removed in large, pressed cakes. Several types of presses are used but each works as described here. One hundred pounds of copra, when expressed by modern equipment, will yield approximately 63 pounds of coconut oil and 35 pounds of oil meal or cake.

The cakes are generally cooked and pressed a second time for further oil expression, and after the second pressing they are prepared for use by livestock. Coconut oil cake is well known in our country in the livestock feed trade. It generally contains from 7 to 10 percent oil and considerable protein, and is commonly used by dairymen in feeding their herds.

For edible purposes the crude oil must be refined. Free fatty acids are removed by alkali, and the oil is deodorized by treatment with superheated steam in vacuo.

Utilization of Coconut Oil

In prewar years about 1.6 million metric tons of coconut oil were produced annually of which about 1.0 million metric tons entered world trade. Only two other vegetable oils—cottonseed and peanut—were produced in this volume, and exports of no other were so great.

Coconut oil has many industrial and edible uses. Its melting point is 72° F. In transporting, the oil leaves the tropics in a liquid state but solidifies when carried to cooler zones. This necessitates the installation of steam heating equipment in tankers carrying coconut oil in bulk, otherwise unloading would be impossible in a cooler climate. Because of its consistency at lower temperatures, the oil is not suitable for use as a salad oil. In the liquid refined state it is odorless and colorless; in the solid state it is white to yellowish.

Coconut oil is used extensively in confectionery and bakery products, cosmetics, emulsions, vegetable shortening and lard-compound, margarine, ointments, salves, perfumery, flavoring and soap. It is an essential ingredient in the manufacture of synthetic rubber. It is used as a plasticizer in many products. It serves as a substitute for cacao butter in the manufacture of chocolate. It is used for batching jute and probably can be used as a fuel for diesel engines. Because of these numerous uses it is consumed in large quantities. The United States is the largest importer and consumer, into which imports during 1935–39 averaged 230,000 short tons of copra and 171,000 tons of crude coconut oil. In prewar years the largest European im-

FIG. 15 (*Upper*). A flue-drier, known as the Ceylon type, for production of copra. In it pieces of coconut are placed on trays through which hot air passes from fires for which coconut shells are used as fuel.

FIG. 16 (*Center*). Harvested coconuts stored two or three months until cured. In the middle foreground some nuts have sprouted. The young plant is nourished by the nut's milk and meat.

FIG. 17 (*Lower*). Carabaos, or water buffaloes, are often used in the Philippines and parts of southern Asia to pull carts loaded with coconuts. (*Photos courtesy Philippine Refining Corp., New York.*).

porters in order of importance were Germany, France, Great Britain, Denmark and the Netherlands. These countries prefer to import copra, express the oil and use the residue for livestock feed. The oil is used for soap-making throughout Europe and for margarine manufacture in Scandinavia. Mexico is the ranking Latin American importer.

In the United States large quantities of coconut oil are used in making nut-margarine, as contrasted to oleomargarine made chiefly from oleo which is a beef fat, and about two-thirds goes for soap-making. Virtually all margarine was made from animal fats three decades ago, but coconut oil has become the most important ingredient. Cottonseed, peanut and palm oil are other vegetable oils used in its manufacture. Consumption of margarine, however, is curtailed in the United States by our excise tax of 3 cents a pound on the domestic processing of Philippine coconut oil, 5 cents a pound on foreign coconut oil, and the tax in many States on margarine compounded of foreign-derived oils.

Coconut oil is solidified for use as margarine by the hydrogenation process which consists of subjecting the oil to hydrogen gas in the presence of a catalyst, nickel. The oil combines with the hydrogen and its melting point is thereby raised. However, the melting point is not raised very much because, unlike most vegetable oils, coconut naturally contains almost as much hydrogen as possible. It is for this reason that its melting point is at 72° F., while that of most vegetable oils is lower.

Vegetable Versus Animal Fats and Oils

There are three major groups of sources from which we derive our fats and oils: vegetable, animal and marine. Oils derived from cottonseed, peanuts, coconuts, rapeseed, soybeans, linseed, olives, palm kernel, sesame and sunflower seed are the most important of vegetable origin. They compete to some extent with each other and with animal-derived fats and oils. Coconut, palm and palm-kernel oil come from the tropics. Peanut oil is produced in the tropics and temperate regions; cottonseed and olive oil are sub-tropical; and linseed, soybean and rapeseed oil come from the temperate region.[6]

Animal fats and oils are chiefly temperate region materials. They come from animals which are best suited to temperate regions and are fed mainly on grain, a temperate crop. The chief animal fats and oils are butter from milk, oleo fat from the fatty tissues of cattle, lard from the fatty tissues of hogs, and mutton tallow from sheep. There are also a number of stearines, tallows and greases which are by-products of the packing industry and of less importance.[7]

Marine oils come from fish. The most important is whale oil which accounts for about two-thirds of the world's marine oil output. This is produced in large quantities by seagoing tank vessels of up to 30,000 tons displacement with a complete whale-oil rendering plant on board for extraction and storage of the oil at sea. Since most of the whales are in the Antarctic, these vessels operate chiefly in those waters. If the international agreements now in force con-

[6] Annual world production of the major vegetable oils during 1935–39 was as follows: Cottonseed oil, 1.7 million tons; peanut oil, 1.7 million tons; coconut oil, 1.6 million tons; rapeseed oil, 1.4 million tons; soybean oil, 1.3 million tons; linseed oil, 1.2 million tons; olive oil, 1.0 million tons; palm oil, 700,000 tons; sesame oil, 700,000 tons; sunflower seed oil, 600,000 tons; and palm kernel oil, 400,000 tons—total 12.3 million tons. Data from Foreign Crops and Markets, 1947, Vol. 43, No. 26, p. 414. Office of Foreign Agricultural Relations, Washington, D. C.

[7] Annual world output of the major animal fats and oils during 1935–39 was as follows: Butter, 3.7 million tons; lard, 3.0 million tons; tallow, 1.5 million tons—total 8.2 million tons. Data from Foreign Crops and Markets, *op. cit.*

tinue, whale oil production will be limited to about 300,000 tons yearly. Production averaged about 600,000 tons yearly during 1935–39.

The annual world output of fish oil—from pilchard, menhaden, herring and shark mainly—totalled 300,000 tons prewar. Fish and whale oil are used to make soap, insecticidal sprays, linoleum and certain paints. They have several industrial uses and, in general, compete with vegetable and animal fats and oils.

During prewar years the annual world output of the chief fats and oils totalled: vegetable, 12.3 million tons; animal, 8.2; marine, 0.9. By individual commodities butter was produced in the largest volume, followed by lard, cottonseed, peanut and coconut oil.

The United States is the world's chief producer of animal fats and oils, especially the largest producer of hog fat, and we have been the leading exporter of lard for many years. Vegetable oils from both the tropics and temperate zone are today competing more sharply than formerly with animal fats in the United States and abroad. Much of the grain of our corn belt is used to produce pork and lard. With increasing competition from vegetable oils, what is the future of this belt? Corn-hog farmers and dairymen have heavy investments in their enterprises, relatively high labor and land costs, and require a large quantity of roughage and concentrate feed to produce their lard and butterfat indirectly by animals. Coconut oil is produced directly from the copra of the coconut palm, and the annual yield of oil per acre is tremendous, derived mainly by cheap native labor. It is estimated that of the total world output of copra, only about 10 percent is produced under more costly plantation culture.

Realizing the competitive position of coconut oil, domestic fat and oil producers have sought tariff protection. Coconut oil is rather essential in soap manufacture, and there is no suitable substitute for it in many kinds of soap. Because of this, imports of it for soap are not too severely opposed, but dairymen do not want the oil imported for use in margarine manufacture, and they seek a tariff at a level to discourage such use.

Shredded Coconut

Large quantities of shredded desiccated coconut are consumed throughout the world. Some of the product is prepared in Europe and the United States from fresh coconuts imported into those areas. Most of it, however, is prepared in the commercial coconut regions, especially in Ceylon, the Philippines and India.

To prepare it, the shell is chipped from the fresh nut with a sharp axe, and the brown testa is shaved off the kernel. The latter is washed in water several times, shredded and then dried in hot-air ovens. It is graded on the basis of fineness of grain and packed in tins or boxes for use in candy, icings, pastry and other items.

Most of the shredded coconut consumed in the United States comes from Ceylon and the Philippines, but about 60 percent of the fresh coconuts imported into the United States is used for shredding, principally in San Francisco and New York. The amount entering into the manufacture of this delicacy can be estimated from the fact that from 1935 to 1939 an average of 42 million coconuts was imported annually into the United States, chiefly from Jamaica, Honduras, Puerto Rico, Mexico and the Central American republics. During the subsequent war imports were drastically curtailed.

Commercial Production of Acids by Fungi

Citric, gluconic, fumaric and gallic acids, all having industrial applications, are the only ones among 41 known fungus acids that are produced commercially today.

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Introduction

THE fungi as a group contain widely diverse types of microorganisms, ranging in size from microscopic to the easily visible mushrooms and puffballs. Their metabolic activities are similarly diverse, and literally hundreds of products are formed in the group. Many of these products are acids; a recent review lists forty-one, and there are undoubtedly many more not yet investigated.

Fungi come to our attention primarily as destructive agents—spoilage of fruits and vegetables, diseases of crops, deterioration of textiles and leather, and molding of stored foods are a few of their undesirable activities. It is instructive to recall, however, that their primary role in nature is beneficial, namely, the decomposition of dead plant and animal residues which would otherwise encumber the earth. The utilization of fungi in industry is similarly to be listed on the credit side for the fungi; it is necessary to mention only the drug penicillin, produced by a fungus, to remind us that the fungi are not necessarily harmful.

Among the hundreds of known fungus products only a few are of industrial importance. There may be no industrial need for a particular compound; it may be produced more cheaply by a chemical process; the fungus may produce too little of it for man to use it; or the separation of the desired product from other metabolic substances may be too expensive. For these and other reasons only a few fungus products are of commercial importance; among the forty-one known acids, the subject of this review, only a handful are of any interest—citric, gluconic, fumaric, gallic, *d*-lactic, itaconic, kojic and oxalic—and only the first four named are actually being produced commercially at the present time.

The fungi concerned in these processes are of the group known commonly as "molds". These are saprophytic organisms, deriving their energy by oxidation of organic compounds, and can be grown in suitable culture media. The mold body consists of numerous microscopic threads which cohere and interwine in large masses to form the mycelium. Reproduction is accomplished by production of large numbers of usually one-celled spores which can be carried great distances by air currents or may be transferred deliberately by the investigator to start new cultures of the organism. Since the molds, like all other fungi, require molecular oxygen, they normally grow on the surface of a medium, forming a mat or pad of growth. However, if air is bubbled through a liquid medium, the growth is no longer restricted to the surface and the organism grows in scattered masses throughout the liquid. These two methods of cultivation, "surface" and "submerged", are both used in the production of acids by fungi; generally, the latter method is preferred if the desired product is formed under submerged con-

ditions, since it is more economical of labor and equipment and since contamination is more easily controlled.

In all industrial microbiological processes the organism is grown in pure culture in or on a medium which supplies it with food. The medium used depends on the mold and on the product desired, but all or almost all contain a carbohydrate source (starch or sugar), a source of nitrogen and some inorganic salts to supply essential elements. These substances may be added as pure chemicals or may be supplied in a crude state; in the citric acid process, for example, carbohydrate may be either refined cane sugar or crude molasses.

It is common practice to refer to all microbial processes as "fermentations", and this usage is followed here. The term is not a good one, since the original definition of it, the definition still used by many, implies anaerobic conditions. Mold processes are all carried out in the presence of oxygen, *i.e.*, under aerobic conditions. By fermentation we refer to any microbial activity resulting in chemical changes in the medium.

While there are a bewildering number of mold genera and species, only a few are concerned in industrial production of acids. These include species and strains of the genera *Aspergillus*, *Penicillium*, *Rhizopus* and *Mucor*. The first two genera named contain some of the familiar green and blue-green molds occurring on fruit; *Rhizopus* and *Mucor* are represented in everyday experience by the black bread-mold. Some of the organisms utilized have a sexual stage, but in routine transfer the asexual spores or conidia are used exclusively.

Citric Acid

This is the most important acid produced industrially by fungi. From a relatively unpromising start in the closing years of the nineteenth century the fermentation method for the production of this compound has been developed by research to a point where no other method can compete with it in cost or product quality.

Historical. Citric acid itself was first isolated, from lemon juice, by Scheele in 1784. Liebig in 1838 determined most of its chemical properties, especially the fact that the molecule contains three acid groups.

In 1893 the history of the industrial utilization of fungi began with the discovery by Wehmer in Germany that a green mold named by him *Citromyces glaber* but now considered to be a form of *Penicillium*, forms citric acid from sucrose solutions. Wehmer and others after him realized the commercial possibilities of this discovery, and in the next decade attempts were made in Germany to develop a large-scale method of production. These attempts failed for a variety of reasons, chiefly that the fundamental knowledge of mold metabolism was not at that time sufficiently extensive to enable the everyday problems of a plant-scale fermentation to be solved.

The next great advance came in the second decade of this century when Zahorski in Germany and Currie in this country discovered that another fungus, *Aspergillus niger*, is a much more efficient producer of citric acid than Wehmer's organism. In addition, Currie and Thom worked out conditions of culture giving high yields of citric acid and a minimum of other, undesirable acids. The first commercial units were put into operation about 1919, although large-scale output was not attained until about 1923.

Economics of Citric Acid Production. Citric acid occurs naturally in many fruits, either as the chief acid or admixed with malic acid. In the latter group belong cherry, strawberry and raspberry. Among fruits almost the entire acidity of which is the result of citric

acid may be mentioned cranberry, pineapple and all citrus fruits—lemons, limes, oranges and grapefruit. Prior to the development of the mycological method, "natural" citric acid from certain citrus fruits was the sole source of supply. Not all of the fruits described are of equal importance as sources of natural citric acid; the great bulk is derived from cull lemons, minor amounts from limes and from pineapple wastes.

Up to 1922 Italy produced about nine-tenths of the world supply of citric acid, chiefly from low grade lemons of Sicily. This was exported, in part as crude calcium citrate, in part as pure acid. The year 1922 was a critical one in the economic history of citric acid. The Italian government moved at that time to restrict, by means of export duties, the outward movement of citric acid and citrates. In the same year the United States raised the import duty on calcium citrate from one to seven cents per pound and on citric acid from five to 17 cents per pound. The new rates were almost prohibitive, and of course the protection afforded by them was a major factor in establishing the domestic citric acid industry. A third factor in the situation at that time was the increased acreage of lemons in California, affording a home source of natural citric acid. Finally, as mentioned previously, the fermentation method began to yield a significant output in 1923.

The net result of these changes is shown by the fact that the dollar value of imported citric acid and citrates fell from $2,701,074 in 1922 to zero in 1929[1]. During the same period domestic production of both natural and fermentation acid rose from 5,689,473 to 10,755,789 pounds per year[2]. The increase over the seven-year period is attributable largely to the growth of the fermentation industry; in 1929 probably 70% of the acid produced came from this source.

The estimated current annual production of citric acid and citrates in this country is 26,000,000 pounds[2]. Of this total the fermentation process supplies about two thirds; citric acid from cull lemons in California and from pineapple wastes in Hawaii makes up the remaining third. Natural citric acid can compete with the mycological process only if the raw material is otherwise a waste product, and for this reason the production of natural citric acid is limited by the tonnage of cull lemons and pineapple wastes available.

Abroad the situation is of course confused by the dislocations of war. Prior to 1939 both natural and fermentation citric acid were produced in several European countries. Fermentation plants are known to have been in operation in Belgium, Germany, England and Czechoslovakia. Plants were probably also in operation in Russia and Japan. European producers of both natural and fermentation acid worked out the International Citric Acid Agreement in 1935 to stabilize prices at a profitable level; details of the cartel agreement were never made public.

In the United States it is believed that only one company is at present engaged in the manufacture of citric acid by the fermentation process. For this reason, production statistics are not published in any detail; estimates of current production are 17,000,000 pounds per year.

Methods of Production. Details of industrial methods are closely guarded commercial secrets. However, published research from non-commercial sources and the patent literature give a general picture of the process. From this background it is clear that the important elements in the fermentation are the choice of the organism, the composition of the medium, the physical conditions

[1] Wells, P. A. and Herrick, H. T. Ind. Eng. Chem. **30**: 255–262. 1938.

[2] von Loesecke, H. W. Chem. Eng. News **23**: 1952–1959. 1945.

(aeration, temperature, design of vessels, *etc.*) and purification of the product.

We have noted that commercial production became feasible only with the introduction of *Aspergillus niger*. This is an extremely ill-defined species, covering in general all of the black-spored Aspergilli; there is no certainty that a culture identified as this species will be physiologically the same as another culture similarly named. In practice the existence of this strain variability creates innumerable difficulties. In the first place the results of one research worker may be diametrically opposite to those of another, and there is no way of telling whether the discrepancy arises from error or from strain differences. A few experimental data are available on the extent of these differences. Workers in Italy found that acid production may be either increased or decreased by the addition of iron to the medium, depending on the strain used. It was early discovered that some strains produce citric acid contaminated with large amounts of oxalic acid, while other strains form a minimum of the less desirable acid.

One significant result of this characteristic is that a commercial producer regards his own strain as an asset of great value, and there is no interchange of cultures or of information. On a more fundamental level, strain variability has two important consequences. First, a given strain may "degenerate"—lose its capacity to produce citric acid. Current biological theory regards such changes as mutations, analogous to those of higher organisms. The manufacturer must maintain stock cultures of his good strains under conditions which minimize change.

A second consequence of strain variability is that a culture may be improved by judicious selection of high-yielding or otherwise desirable variants which arise by mutation. Furthermore, the frequency of mutation may be increased by bombardment of spores with ultra-violet rays, X-rays or neutrons. With a larger number of mutants to choose from, the chances of obtaining a superior strain are greater. Encouraging results have been obtained by workers at the University of Cincinnati, using these mutation-inducing techniques on *Aspergillus niger*.

While *A. niger* is the only fungus used industrially, significant amounts of citric acid have been reported to be formed from sugar by several other fungi. Among these are other species of *Aspergillus;* at least seven are known. A few other molds—species of *Penicillium* and *Mucor*—also produce citric acid. Two other fungi, *Botrytis cinerea* and *Ustulina vulgaris* form considerable quantities of citric acid. Apart from the fungi only one doubtful case of citric acid synthesis exists: a patent was issued in 1936 for a process involving the formation of citric acid from acetic acid by a yeast.

In the commercial production of citric acid, spores of the mold are sown on the surface of a sterilized liquid medium contained in shallow aluminum pans. The spores germinate, forming in two or three days a firm mat of mycelium over the surface. The fermentation is complete in seven to ten days at 25° to 35° C. (77° to 95° F.), when 90% of the sugar present has been utilized. Commercially about 60% of the sugar present can be recovered as citric acid; higher yields are obtained under laboratory conditions.

The size, shape and composition of the container have a marked effect on the yield. Fungi in general require really large amounts of oxygen, and the citric acid organism is no exception. Experience has shown that the ratio of the surface area exposed to the air to the total volume of the medium is critical; the optimum ratio lies between 1.0 and 2.0. It is believed that commercial production

utilizes a pan three feet square and two to three inches deep. Air may be blown across the pan to increase the available oxygen supply.

It can be calculated that the present production of fermentation citric acid requires the continuous use of 30,000 to 40,000 pans of the above dimensions if this is the only type of container used. The area covered by this number of pans reaches the staggering total of seven to nine acres.

Since metals like iron and lead are toxic even in very small amounts to the fungus, the material of which pans are made is of importance. Aluminum of the highest obtainable purity seems to be the most practicable material from the standpoint of initial cost, durability and freedom from toxic effects.

In view of the problems involved in handling large numbers of pans it is not surprising that efforts have been made to substitute some less cumbersome method. These efforts have been made in two directions: maintenance of a favorable surface-volume ratio by use of a porous substrate, and maintenance of an adequate oxygen supply in a large container by supplying air under pressure.

The Cahn method, patented in 1931, involves the first-named of these principles. A solid but finely divided substrate is impregnated with a nutrient solution; Cahn suggested sugar cane bagasse or sugar beet pulp. A yield of 45% in 38 to 60 hours was claimed for this method. A recent report from Eire suggests use of a sawdust or sphagnum moss base impregnated with nutrients.

The ideal solution to the aeration problem would be to supply air through a "sparger", or perforated ring, directly to the culture medium; such "submerged culture" or "deep tank" methods have been especially successful in the penicillin industry. It has not yet been possible to utilize submerged culture in the production of citric acid. The first even partially successful attempt was made in 1930, and the yields were very low. However, three patents have been issued in the last five years for submerged culture methods. One of the more fully described of these calls for a large cylindrical tank of nutrient medium, air being supplied under pressure and being distributed by rapid stirring (300 rpm). The difficulty of all of the deep tank methods patented or described so far seems to be that for maximum yields the fungus must be grown in one batch of medium. This medium must then be removed and a fresh "fermentation" medium added; citric acid is recoverable only from the second batch. This manipulation will be costly on a large scale, and the length of time required is great.

These and related submerged methods deserve further research. If the yield and fermentation times could be brought into line with those of the shallow pan method, the large number of pans now required could probably be replaced by 50 to 100 large fermenters of the type and capacity used in the penicillin industry.

While *Aspergillus niger* can form citric acid from an amazing variety of other carbon compounds, sucrose is the preferred raw material for the fermentation. Individual investigators have reported success with crude molasses as a source of sucrose, but there is evidence that the industry has been forced to use more highly refined sugar. Recent work at the University of Wisconsin has established that inorganic constituents (metals) of molasses may be deleterious and that these metals can be removed from crude molasses by chemical treatments.

The concentration of sugar used is high for a microbiological medium, 15% to 20%. At lower sugar levels the fungus will attack citric acid for energy with consequent poor yields.

The citric acid mold, like any living

organism, must be provided with certain inorganic chemicals. Nitrogen may be supplied as inorganic ammonium nitrate or, less commonly, as urea. Magnesium, potassium, sulfur and phosphorus are also added to the medium, although the concentrations recommended vary widely. In addition, a still uncertain group of "trace elements" must be supplied; recent work indicates that manganese, iron, aluminum, zinc and chromium at proper concentrations improve yields. Probably at least minute amounts of other elements are required but are present in adequate amounts as impurities in the other constituents of the medium.

Finally the acidity of the medium is of paramount importance. Failure to realize this was in large part responsible for the early difficulties in establishing the commercial process The medium in current use is very acid, the initial pH being 1.6 to 3.0. If the pH is much higher, large amounts of oxalic or gluconic acid may form in place of the citric acid desired.

Table 1 contains two recommended media, that of Doelger and Prescott for shallow-pan cultivation, and that of Karow for the newly developed submerged method employing *Aspergillus wentii*.

The medium of Karow is a replacement medium, hence is low in phosphorus and deficient completely in magnesium; presumably these elements are needed for growth but not for the actual process of conversion of sugar to citric acid.

It is not possible at present to outline the course of the biological conversion of sucrose to citric acid. A favorite theory in the older literature is that any substrate is broken down to alcohol or acetic acid and the citric acid synthesized by a series of condensations of smaller molecules. The high yields obtained—over 80% of the sugar used—are believed to refute this theory, but even this refutation is not secure now, since it has been discovered recently that atmospheric carbon dioxide may enter the reaction and contribute carbon to the citric acid molecule. In spite of its great scientific and practical interest, the intermediate steps in the biosynthesis of citric acid are not known.

Most of the evidence indicates that, biologically speaking, the formation of large amounts of citric acid is an "abnormal" process. The normal oxidation of sugar by fungi is more nearly complete, resulting in simple end-products like oxalic acid and carbon dioxide. By supplying an excess of sugar, by maintaining a very high acidity and perhaps

TABLE 1
CITRIC ACID MEDIA

Doelger and Prescott*		Karow†	
Ingredient	Concentration, grams per liter	Ingredient	Concentration, grams per liter
Sucrose	140.0	Sucrose	158.0
NH_4NO_3	2.23	Urea	0.5
K_2HPO_4	1.00	KH_2PO_4	0.05
$MgSO_4 \cdot 7H_2O$	0.23	KCl	0.15
		$MnSO_4 \cdot 4H_2O$	0.02
		$ZnSO_4 \cdot 7H_2O$	0.01

* Doelger, W. P. and Prescott, S. C. Ind. Eng. Chem. **26**: 1142–1934.
† Karow, E. O. Proc. Soc. Amer. Bact. **1947**: 41. 1947.

by restricting the supply of essential catalytic agents (phosphate, growth factors), man prevents the oxidation of sugar from following its normal course. In line with this interpretation is the observation that too good growth of the mold results in diminished yields of citric acid.

Returning to the industrial process, at the end of the fermentation the fungus growth is separated from the culture liquid by filtration. The mat is pressed to remove any absorbed acid and is then discarded. The combined filtrate and press-juice are then neutralized with calcium hydroxide; calcium citrate precipitates on heating. A large part of the acid is marketed as the calcium salt; if pure acid is desired it is easily liberated by acidification with sulfuric acid. Preparation through the barium salt has also been suggested. Commercial yields are probably about 60%, *i.e.*, 60% of the sugar is converted to recoverable acid.

Zender in 1937 patented a process by which residual sugar is removed from the culture fluid by a yeast fermentation, followed by concentration, purification with charcoal and direct crystallization of the free acid.

Utilization of Citric Acid. Citric acid finds a variety of uses in medicine, food technology and industry. Over half is used in medicine, chiefly as the calcium salt, which is of value as an alkalinizing agent and as an easily assimilable source of calcium for human nutrition.

Last available figures credit the food and beverage ind try with consumption of about one-four n of the total citric acid produced in this country. The free acid finds extensive use in the preparation of soft drinks and artificial flavors. Sodium citrate is a valuable emulsifying agent for milk and milk products such as cheese, evaporated and condensed milk, and ice cream.

In other fields of technology citric acid is used as a silvering agent, as an ingredient of engraving inks and as a supplementary chemical in dyeing and calico printing. In Italy citric acid has been used as a starting material for the synthesis of antipyrine and of certain azo dyes.

The esters of citric acid are of particular interest today because of their applicability in the rapidly developing field of plastics and synthetic resins. These esters are made by a fairly simple reaction with ethyl or butyl alcohol. Each molecule of acid unites with three of alcohol to form a tri-ester. Both triethyl citrate and tributyl citrate are excellent solvent plasticizers for cellulose esters and ethers, *e.g.*, cellulose nitrate, ethyl cellulose and cellulose acetate, and for phenolic resins. As plasticizers these esters are added to increase the flexibility and extensibility of the plastic. Triethyl citrate can also be used as a solvent plasticizer for vinyl resins; use of this ester imparts resistance to discoloration by light. Tributyl citrate serves as a plasticizer for lacquers; its low solubility and volatility make it suitable for products which must resist weathering.

Additional more complicated derivatives of citric acid, acetyl triesters, have been prepared and found to have potential value in the manufacture of cellulose acetate textiles and of resistant lacquers.

Other related acids—aconitic, citraconic, itaconic and mesaconic—can be prepared from citric acid. Esters of some of these may offer promise in the plastics industry similar to that of the citric acid esters. Tributyl aconitate, for example, can be used as a plasticizer for certain types of synthetic rubber.

Gluconic Acid

General. Gluconic acid results from the oxidation of glucose; unlike citric acid the process is a relatively simple one-step enzymatic oxidation. The enzyme responsible has been isolated in a par-

tially purified form. It is interesting that this enzyme exerts an antibacterial effect, since a product of the reaction is hydrogen peroxide, toxic to many bacteria. In the early days of work on penicillin a second antibiotic was found in cultures of *Penicillium notatum*. It was named, in fact, "notatin", but later work showed its identity with the glucose-oxidizing enzyme previously known and that its antibiotic activity is of no practical importance.

Gluconic acid was first isolated as a microbial product in 1878 by Boutroux in France from a bacterial culture. In 1922 Molliard found a strain of *Aspergillus niger* which produced both citric and gluconic acid. Investigators in Germany, Russia and The Netherlands have contributed to our knowledge of the process, but most of the detailed information comes from a long continued and successful study by a group in the United States Department of Agriculture.

Biologically the oxidation of glucose is a means by which the fungus obtains energy. There is some evidence that gluconic acid accumulation is greatest under somewhat poorer growth conditions. With more vigorous growth the acid itself is utilized and the yield suffers.

Production of gluconic acid in the United States in 1939 was 500,000 pounds[3]. The entire annual amount is produced by fermentation methods, these having driven out the older chemical process.

Methods of Production. The property of accumulating gluconic acid is restricted to relatively few fungi, chiefly certain species and strains of the genera *Aspergillus* and *Penicillium*. Other genera, *e.g.*, *Mucor*, *Monilia* and *Fusarium*, accumulate little or none. In early studies on the process certain Penicillia were used, particularly *Penicillium luteum-purpurogenum* and *P. chrysogenum*. Since about 1937 a selected strain of *Aspergillus niger* has been found better, both on account of its ability to form gluconic acid and on account of the fact that it sporulates abundantly and is therefore easily transferred to new cultures.

It is striking that both citric and gluconic acid—very different chemically and probably unrelated biologically—should be produced by strains of the same species. More than that, either strain is able, under certain circumstances, to produce the acid characteristic of the other. The key is in the "circumstances", the environment. In a very acid medium citric acid predominates, while in a medium only slightly acid the main product is gluconic acid. A further example of the varied processes carried on by a single organism is found in *Aspergillus fumaricus:* this organism produces gluconic and citric acid in all media but in some media may produce also fumaric and oxalic acids. Fungi which produce chiefly lactic acid usually produce a small amount of fumaric acid. Industrial utilization thus depends on isolation of a mold producing the desired acids and on discovery of the conditions under which the accumulation of other acids is at a minimum.

Several bacteria of the genus *Acetobacter* produce gluconic acid in culture, and patents for the use of these have been issued. The fermentation is, however, slow, and it is believed that no gluconic acid is at present produced commercially from bacteria.

Turning from the choice of organism to the methods of cultivation, it is to be noted first that early work was conducted on the basis of surface culture of the fungus. In general, this resembles the shallow-pan method still in use for the production of citric acid. The surface fermentation was carried out with a glucose medium in aluminum trays; the yield was about 65% in eight to 14 days.

[3] Wells, P. A. and Ward, G. E. Ind. Eng. Chem. 31: 172–177. 1939.

Interest in other methods of cultivation began when it was demonstrated in Germany that gluconic acid fermentation can be carried out in submerged culture if air or oxygen in sufficient quantity is bubbled through the medium. American workers soon thereafter confirmed these results and devised large-scale equipment for laboratory research on the submerged process.

One of the favorite types of apparatus is the rotary drum. As the name implies, the fermenter is barrel-shaped and is so mounted that is can be rotated on its long axis. The medium is placed in the drum—usually occupying 40% to 50% of the total volume—and the apparatus and medium are sterilized with steam. The drum is so constructed that after inoculation sterile humidified air can be blown through under pressure. The air so supplied is brought into intimate contact with the medium through the rotary motion of the drum; baffles and buckets are so located in the drum that the medium is thoroughly aerated.

Instead of the rotary drum the usual type of tank fermenter may be used. A large cylindrical tank is provided with a power-driven stirrer, and the medium contained in it is thoroughly aerated by means of compressed air blown in through many small holes in the ring-shaped sparger lying at the bottom of the tank. The two methods differ only in detail, the principle being the same.

From the published work of the Department of Agriculture investigators we can briefly summarize as follows the steps involved in production of gluconic acid in a large rotary drum fermenter of commercial or at least pilot plant size.

Aspergillus niger is maintained in culture on a solid medium containing 3% glucose. After seven days spores are transferred to small flasks containing 5% glucose. Growth on this sporulation medium provides in about a week an abundance of spores for further inoculations. The next step is transfer of the organism to a small rotary drum containing two to three gallons of medium; this drum operates as just described. After 24 hours in the small drum, the entire contents are transferred to the large fermenter. Use of this "pre-germinated" inoculum speeds up the final fermentation and permits more economical use of the large fermenter.

In the work described, an aluminum drum of 420 gallons capacity is used, with about 175 gallons of medium. The drum is rotated slowly (13 rpm), and air is supplied at the rate of 37.5 volumes of air per volume of medium per minute. The temperature is maintained at about 30° C. (86° F.) by means of a water spray, since the reaction generates heat. Under these conditions it is possible to convert 200 pounds of corn sugar to gluconic acid in 24 hours with a yield as high as 97% of the sugar consumed.

The usual carbohydrate raw material for the fermentation is refined corn sugar, about 92% glucose. Other materials in the medium include ammonium phosphate, magnesium sulfate and potassium phosphate. Corn steeping liquor, one of the residues of corn starch manufacture, is added in small amounts (0.2 to 0.3%).

The critical distinction between this medium and that used for citric acid formation by the same mold species is that the medium for gluconic acid production is made much less acid by the addition of 2.6% calcium carbonate. The slight acidity maintained (pH 5.5–6.5) affords optimum conditions for the formation of gluconic acid to the practical exclusion of other acids.

Until recently the concentration of glucose had to be restricted to less than 20%. At higher concentrations more acid is formed, but this involves one of two difficulties. Unless the increased product is neutralized the pH drops to a level which inhibits the fermentation.

However, if calcium salts are added to effect neutralization of the acid, the concentration of calcium gluconate exceeds the solubility of this compound and the crystallized salt again interferes with the fermentation by forming a crust on the fungus mycelium.

This problem was solved in 1940 by the Department of Agriculture workers. They found that addition of small amounts of boron compounds, boric acid or borax, greatly increases the solubility of calcium gluconate. A strain of *A. niger* tolerant of boron was selected; with this strain and a boron concentration of 0.1% the glucose concentration can be increased to 25%, resulting in considerable economy, since the percentage yield remains above 95%.

Finally it has been shown that replacement techniques are entirely feasible. After one batch of medium has been fermented it is drawn off, but the fungus mycelium is left in the fermenter. Fresh medium is then added, and the mycelium ferments the sugar in it; the process can be repeated at least 12 times. Using a single large fermenter the introduction of the replacement technique resulted in a 45% increase in yield.

Using these methods yields of over 95% are regularly obtained with large scale equipment in a 24-hour fermentation. Taking as an example the fermenter holding 140 gallons of medium, the yield of acid every 24 hours is about 300 pounds. It has been reported that the use of a plant-scale fermenter equipped with a power-driven agitator shortens the fermentation period to eight hours.

The acid is recovered from the fermentation medium by a relatively simple process. After removal of the mycelium by gravity or pressure filtration, the mash is neutralized with calcium hydroxide and allowed to stand 24 to 48 hours, at the end of which time the first crop of crystals of calcium gluconate is removed by centrifugation. A second crop is obtained after concentration of the mother liquors. The crystals of calcium gluconate are washed twice in cold water and dried in aluminum pans at a moderate temperature.

Uses of Gluconic Acid. The great bulk of the acid produced is utilized as the calcium salt for pharmaceutical purposes. Calcium gluconate is a safe and effective means of supplying calcium to the human body; it may be administered orally or by injection. In the body the gluconate radical is assimilated and the calcium is made available. Calcium gluconate finds a use also in veterinary medicine, in the treatment of milk fever of cattle.

Other salts of gluconic acid are used pharmaceutically in the same way. Iron and copper gluconates are used in the treatment of anemia to supply the body with needed metals.

Free gluconic acid has some industrial possibilities, including use as an acidifier in pickling and polishing metals, in laundry sour and in washes for milk equipment. It is not at present utilized in significant amounts by industry.

Fumaric Acid

General. The discovery that fungi produce fumaric acid was made by Ehrlich in 1911, working with *Rhizopus nigricans*. Wehmer found in 1918 that an *Aspergillus* species produced the same acid, although 10 years later he reported that the organism had lost this synthetic power.

Methods of Production. The ability to form fumaric acid in quantity is possessed by relatively few fungi, most of them in the Mucorales. Known strains able to accumulate fumaric acid occur in the genera *Rhizopus*, *Mucor*, *Cunninghamella*, *Circinella*, *Aspergillus* and *Penicillium*. As in the case of other fungus products, the effect of strain differences is profound; strains which are otherwise

identical may differ widely in the amount of acid formed. It is very likely that all fungi, and probably all living cells, produce fumaric acid during the oxidation of carbohydrate. In most cells the acid is metabolized as soon as formed, so that only traces exist at any one time. In a few exceptional organisms it appears that some derangement of the usual cycle has occurred, and fumaric acid accumulates; even with these organisms fumaric acid may be slowly broken down.

In most of the published work spores of a selected strain of *Rhizopus nigricans* have been sown on the surface of a liquid nutrient medium. When the acid concentration reaches its peak the fermentation is discontinued and the fungus growth separated from the acidic culture fluid. It is possible, however, to shorten the fermentation time by using submerged culture methods; the medium is aerated and stirred to provide oxygen, and the organism grows throughout the entire volume. Stationary cultures require five to seven days, submerged cultures 24 to 48 hours for completion of the fermentation.

Starch, invert sugar and a variety of simple sugars can be converted to fumaric acid; usually refined corn sugar (glucose) is used in fermentation media. Salts include sources of nitrogen, potassium, magnesium, phosphorus and sulfur. Best results are attained when the ratio of carbohydrate to nitrogen is high. A typical medium contains 10% glucose, 0.2% ammonium sulfate, 0.05% magnesium sulfate and 0.05% dipotassium phosphate. In addition, a neutralizing agent, usually calcium carbonate, is added to prevent development of too high acidity.

In 1939 workers at the New Jersey Experiment Station reported that zinc exerts an inhibitory effect on the formation of fumaric acid, probably because this element catalyzes the complete oxidation of carbohydrate to carbon dioxide and water. Iron exerted a favorable influence on fumaric acid accumulation. These results were applied to commercial production in a process patented in 1943. In this process the fungus is grown two to seven days on a medium containing zinc to encourage heavy growth. This medium is then replaced by a fermentation medium containing iron salts, in which the conversion of sugar to fumaric acid is carried out rapidly.

The yield of fumaric acid may be as high as 50%, *i.e.*, half of the sugar may be converted to acid. Yields are especially high in replacement methods. The methods used in industry for recovery and purification are not known precisely. In the laboratory the mycelium is removed by filtration and the acid separated from the filtrate as the insoluble calcium salt.

Uses of Fumaric Acid. Fumaric acid is not at present used in as large amounts by industry as are citric and gluconic acids. Experimentally it has been shown that it can be used to replace tartaric acid in leavening agents; the toxicity of fumaric acid is even lower than that of tartaric acid. Esters of fumaric acid can be polymerized to form a series of plastics of varying characteristics. Other uses are likely if the cost of the product becomes lower.

Gallic Acid

Gallic acid, unlike other acids considered so far, has a history prior to modern mycology. In the old pre-scientific process plant material containing tannin was moistened and allowed to ferment naturally for about a month. Gallic acid was recovered from the mass by leaching and concentration of the leachate.

In 1867 Van Tieghem, a pupil of Pasteur, investigated the process in its relation to the then revolutionary concepts of microbiology. He found that the fungi of the genera *Aspergillus* and *Penicillium* are able to hydrolyze tannin to

gallic acid. The next advance was made in 1902 by Calmette, who discovered that an *Aspergillus* species can hydrolyze tannin to gallic acid in submerged culture.

Present-day fermentation of gallic acid is obtained by modifications of the Calmette process. The preferred natural source of tannin is the "gallnut" of sumac or oak, a swelling developed on the plant following an insect sting. A clear water extract of tannin is made from crushed gallnuts, and its concentration is adjusted to a specific gravity of 10° to 20° Baumé. This extract is sterilized and inoculated with spores of *Aspergillus niger*, grown on a solid medium containing rice and wheat bran. During the fermentation, which requires 10 to 20 days, the mixture is agitated mechanically and aerated with large volumes of sterile air. The yield is usually 10 to 20 grams per 100 ml. of tannin extract.

The formation of gallic acid from tannin differs from other fermentations yielding acids in that the process is a simple hydrolysis; the enzyme "tannase" is responsible for the hydrolysis, and can be separated in an active form from the fungus mycelium producing it.

Gallic acid can be prepared chemically from tannin by acid hydrolysis, and this method is used commercially by some producers. Production data on the fermentation process are not available; it is known, however, that the fermentation process is used commercially in both the United States and Europe.

Gallic acid has several important uses in industry. It is the basis for the wool dye alizarine. With ferrous sulfate, gallic acid is responsible for the black color of ink. Small amounts are used in the production of bismuth subgallate, a medicinal product used in treatment of certain skin diseases. Gallic acid is, finally, the starting point in the synthesis of pyrogallol, used extensively as a photographic developer.

Lactic Acid

The production of lactic acid by fungi has been known since 1894. Industrially the process so far has not been developed far enough to compete with the established fermentation method employing bacteria. This bacterial fermentation accounts for all of the 5,000,000 pounds of lactic acid produced annually in the United States.

Among the fungi only one group, known to systematists as the Mucorales, produces lactic acid; as in the case of other fungus products, strain variation is very important, and even closely related strains may differ widely. Most of the experimental work has been performed with a selected strain of *Rhizopus oryzae*. This organism produces lactic acid either in surface or submerged culture; as in other fermentations, the latter is preferred.

Fungus lactic acid has been produced experimentally in the rotary-drum fermenter described in connection with gluconic acid. The best medium contains glucose, urea, salts and calcium carbonate. Yields of 75% in 24 to 36 hours have been reported using this medium.

Several advantages have been claimed for the mold process over the usual bacterial process. The use of urea as a nitrogen source makes purification of the acid much easier. The lactic acid bacteria require complex organic nitrogen compounds; the presence of these in the medium makes preparation of the highly purified edible grade of acid dependent on expensive solvent extraction methods. The mold lactic acid process is somewhat more rapid than the bacterial. Finally the mold produces only the dextro form of lactic acid; as usually run, the bacterial process yields a mixture of the two optical forms of the acid. Competitive advantages of the bacterial process include simpler equipment, no requirement of absolute sterilization and

the utilization of low-cost carbohydrate sources.

Lactic acid is industrially the most important of the group considered here. Four-fifths of the annual production is used by the leather industry to remove lime from dehaired hides and to "plump" leather. Ethyl lactate is used as a solvent for nitrocellulose in pyroxylin lacquers. The food and beverage industries require appreciable amounts of lactic acid as a curing and preserving agent, in soft drinks, fruit juices and candy, as a pickling agent for olives and in the manufacture of beer.

Itaconic Acid

Itaconic acid, an unsaturated dicarboxylic acid, was first reported formed by fungi by Kinoshita in Japan in 1931. He used *Aspergillus itaconicus*. Somewhat later, in 1939, English workers found that certain strains of *A. terreus* produce the acid. Recent studies have been undertaken by scientists of the U. S. Department of Agriculture, and it is to this group that we owe most of our detailed knowledge of the process.

Selected strains of *A. terreus* produce itaconic acid on a medium containing glucose, ammonium nitrate, salts and corn steeping liquor. The acid may be produced either in surface culture or in submerged (agitated and aerated) culture; yields are somewhat higher in the latter case. The best yield reported is 47%, on the basis of glucose consumed. Recovery processes are relatively simple, and acid of 97% purity can be prepared.

There is at present no industrial market for itaconic acid. Until the development of the fermentation process the chemical was both rare and expensive, these factors discouraging research on utilization. The structure and properties of itaconic acid suggest that it can be used in the preparation of alkyl resins and other plastics. Other properties indicate that the acid can be employed in the manufacture of synthetic detergents. These uses are to be envisaged as a result of the relatively low cost of the fermentation process, a cost which can probably be still more reduced by further research.

Kojic Acid

Kojic acid is at present only a curiosity, having no industrial importance. Its structure is of interest from the biochemical point of view, since it is similar in some respects to the ring structure of glucose.

Kojic acid is produced by a few bacteria and by many molds of the genera *Aspergillus* and *Penicillium*. *A. flavus* is the most prolific producer, yields of 50% to 60% being obtained on a medium containing glucose, ammonium nitrate and salts. It has a slight antibacterial action but is too toxic to be of any promise as an antibiotic.

Oxalic Acid

The production of oxalic acid in considerable yield is characteristic of a group of fungi, but the process has never given promise of being able to compete with chemical methods of preparation. It may, however, be profitable to purify the acid from the residues of citric acid fermentation, since the strain of *Aspergillus niger* used in that process usually produces appreciable amounts of oxalic acid. Salts of oxalic acid are used in the preparation of blueprint paper and in bleaching cellulose materials, such as straw.

Hemp—*Production and Utilization*

United States annual production of this formerly very important bast fiber has fallen from about 75,000 tons a century ago to about 2,000 tons today. Imports, too, have dropped. Other fibers, particularly abacá, have replaced it more and more.

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U. S. Department of Commerce

Description

HEMP is a strong, lustrous and very durable, though harsh, bast fiber from the inner bark of the hemp plant, *Cannabis sativa* L. (true hemp), cultivated mainly in Italy, Russia, Turkey, Yugoslavia, Hungary, China, Japan, Chile and the United States. In the last mentioned it is grown particularly in Illinois, Iowa, Indiana, Minnesota, Kentucky and Wisconsin. It is a soft or stem fiber, as are jute and flax, in contrast with the hard or leaf fibers represented by sisal and abacá.

Some confusion exists in the use of the term "hemp" inasmuch as it is frequently used in describing certain other fibers. This practice is exemplified by the use of such misnomers as "Manila hemp" for abacá (*Musa textilis* Née), "sisal hemp" for sisal or henequen (*Agave Fourcroydes* Lem.), "New Zealand hemp" for phormium (*Phormium tenax* Forst.), "Indian hemp" for jute (*Corchorus capsularis* L.), "Mauritius hemp" for furcraea fiber (*Furcraea gigantea* (D. Dietr.) Vent.) and "Sunn hemp" for crotalaria fiber (*Crotalaria juncea* L.), none of which is true hemp.

Hemp is one of the oldest of known textile fibers. There is record of it having been cultivated in China for fiber 27 centuries before the Christian era, and, in fact, until about a century ago hemp and flax were the chief textile fibers of vegetable origin.

Hemp line is hemp fiber that has been scutched and prepared so that the fibers lie straight and parallel. Hemp tow is short or tangled hemp fiber that has been beaten out in scutching the long fiber; or hemp fiber produced from short or tangled stalks.

Preparation and Seeding of the Crop

Hemp is an annual herbaceous plant with a slender, erect stalk three to ten feet tall, 1/6 to 5/6 inch in diameter, and without branches if crowded in broadcast culture, as it is grown for the production of fiber. If grown in checks or drills and cultivated for seed production, the stalks often attain a height of 12 to 16 feet and a diameter of 2/5 to two inches and bear spreading branches. Ideal stalks for fiber production are about 1/5 inch in diameter and about six feet tall. Larger and thicker stalks have more wood and less fiber and are difficult to handle. The leaves are palmately compound and have seven to 11 leaflets.

Hemp for fiber production requires a temperate climate and a rainfall of at least 27 inches per annum with abundant moisture during germination of the seeds and until the young seedlings are well established.

The land for growing hemp must be prepared by thorough plowing and repeated harrowing so as to make a fine mellow seedbed, as uniform as possible

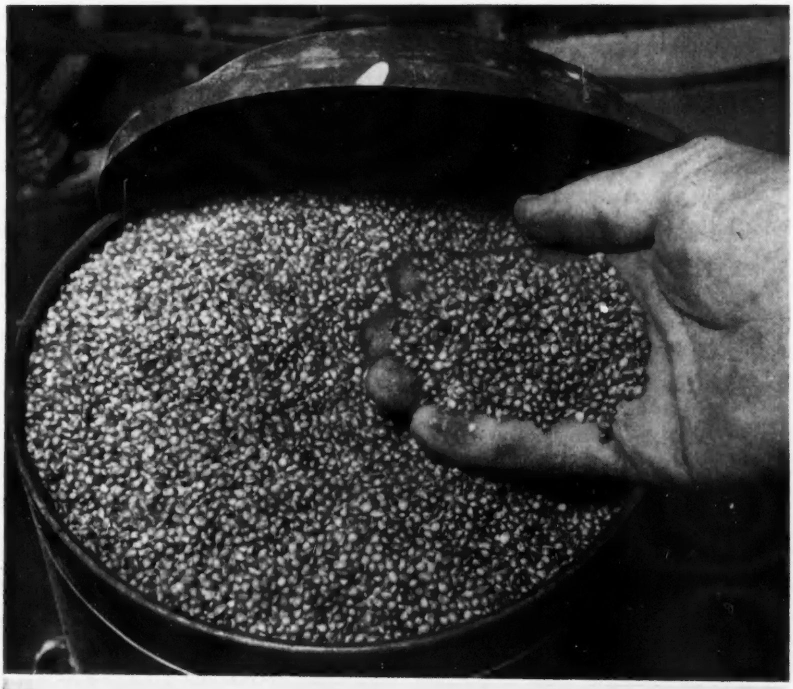


FIG. 1 (*Upper*). Hemp seed in the planter box of a corn planter ready to be sown in a Kentucky field. (*Courtesy U. S. Dept. Agr., photo by Forsythe*).

FIG. 2 (*Lower*). Shocks of unretted hemp on the farm of Robert T. James, Lexington, Ky. The hemp stands in the shocks until early winter when it is spread out to dew ret. (*Courtesy U. S. Soil Conservation Service*).

over the entire field. Seed is sown at the rate of about one bushel or 44 pounds per acre as early in the spring as the land can be worked to good advantage. The seed may be sown broadcast by hand and covered with a light harrow, or it may be sown with a grain drill. Most grain drills, adjusted for wheat or oats, cover the seed too deeply for hemp. The seeds of hemp ought not be covered more than one inch deep. Roller-disk drills often give better results than the more common tooth drills. Sometimes good results are obtained with the tooth drills by removing the teeth so that the seed will fall on the surface of the ground, to be covered with a light harrow following the drill. Rolling the land after seeding is often beneficial. Good hempseed should germinate at least 95 percent. It is always best to have samples of the seed tested for germination before sowing.

Harvesting

In four months after seeding, the crop is ready for harvesting. Some early strains from Manchurian seed or other northern-grown seed may reach maturity in three months, but the yield of fiber will be smaller, since a longer time is required for the plants to lay down cellulose in the fibers. The largest yield of fiber of the best quality is obtained if the hemp is harvested when the staminate flowers are beginning to open and shed pollen. In some regions it has been customary to permit the hemp to become fully ripe so as to obtain fiber and seed from the same crop. When this is done, however, the fiber is harsh and brittle, and the seed lacks vitality. The fiber from hemp that has been harvested so late that many seeds have matured does not possess as good cordage and textile characteristics as fiber from hemp harvested earlier. Hemp stalks should be relatively free of leaves, except a few at the very top, before harvesting. This is important when hemp is shocked after harvest, as it makes the top of the shock smaller so that less rain can enter the shock.

Proper Retting Very Important

The term "retting" is a technical form of the word "rotting". It designates the process of retting or decomposition of the green coloring matter (chlorophyll) and the thin-walled tissues surrounding the fibers in the inner bark by means of which the bark and fibers become free from the inner woody shell of the stalk. Some of the gums and pectose elements cementing the fibers together are also dissolved, and the strands of fiber are partly freed from each other. If the retting is continued too long, it causes too much of the cementing materials to be destroyed, and the fibers become weakened. A series of certain groups of bacteria that are always present are the active agents in the process of retting. Most hemp is retted by spreading the stalks on the ground in thin uniform layers, or swaths, and leaving them exposed to the weather three to eight weeks. Warm moist weather hastens retting, and cool dry weather retards it. Light snow melting on the stalks is favorable for retting, but if the stalks are buried under a heavy snow for a month or more they are likely to be overretted and the fiber ruined.

Water-retting is practiced most extensively in Italy and in some parts of Russia, Hungary and Yugoslavia. The stalks are tied in bundles and placed in slow-running streams or in shallow water near the shores of larger rivers. With water at a temperature of 60° to 70° F., hemp will ret in ten to 15 days. Higher temperatures result in more rapid retting. When the bark, including the fiber, separates easily from the woody inner portion of the stalk, the retting is completed and the bundles of stalks are taken out of the water and set

FIG. 3 (*Upper*). Harvesting hemp in Kentucky.

FIG. 4 (*Lower*). Kentucky hemp grown in 1941 and properly weathered, being hauled to a decorticating plant near Versailles, Ky., where machinery breaks the stalks and removes the hurds or pithy portion from the fiber. (*Photos courtesy U. S. Dept. Agr., by Forsythe*).

up to dry. Another method of preparing hemp fiber in some parts of China and Japan is by steaming the stalks, after which the bark, including the fiber, is peeled off by hand and then scraped to remove the thin outer skin, the coloring matter and most of the thin-walled tissues surrounding the fibers. This fiber, however, is too stiff and ribbon-like to spin well in ordinary hemp-spinning machinery.

Chemical retting has received much attention in the press during the past 50 years. Numerous chemical treatments have been tried, but none of them can be regarded as satisfactory on a commercial scale.

Preparation for Market

Hemp fiber is separated from the retted stalks and prepared for market by two mechanical processes, breaking and scutching. The stalks are first dried, then the woody interior portion is broken into short pieces called "hurds". This process is known as "breaking" and is performed by various methods in different countries. The loosened fiber is separated from the hurds by different methods of beating and scraping, a process called "scutching". Scutched hemp fiber is further cleaned and split into finer strands by being drawn by hand over hackles, or sets of upright steel pins. However, most of the work of hackling is now done with machine hackles in the spinning mills.

In the form of scutched fiber, hemp is composed of groups of strands in flat ribbons 1/50 to 1/5 inch wide and 40 to 200 inches long. It is split into finer strands by hackling. Dew-retted hemp is gray, and water-retted hemp is usually cream white.

Use of Hemp Fiber

The principal uses of hemp fiber in the United States are for the manufacture of fine cordage, commercial twines, threads and packing. Commercial hemp twines cover a wide variety of products, such as finished twines, wall-paper twines, mattress twine, wrapping twine, upholstery spring twine, bag or sack sewing twine, broom twine, hop twine, shipping tag twine, ham strings, bell cord, gas meter cord, hat blocking cord and yarns for weaving into belts and webbing.

Hemp packing is used in packing valves and pumps. Oakum, which is produced from the poorer grades of hemp tow, is tarred and used for both marine work and plumbing. Marine oakum is employed in calking the joints of various kinds of pipe, such as bell and spigot, iron, soil, water supply, waste, sewer and gas.

In 1940 approximately 75% of the domestic hemp production was used in the manufacture of twine (for brooms, brushes, mattresses, upholstery, sail twine and miscellaneous twines), 22% for the manufacture of tarred cordage, and the remaining 3% for other uses (including nets, shoe thread, carpets, webbing and bags). The purpose of the American hemp defense program, discussed later in this article, was to produce enough additional hemp to be used as an extender in the production of sisal rope. It developed that hemp was mixed successfully with sisal and henequen and helped considerably to tide the United States over its wartime fiber needs until the new Central American abacá plantations came into production on a larger scale.

Substitutes

Competing with hemp in its various uses are other soft fibers such as flax, jute and cotton, and hard fibers such as sisal and henequen, abacá, istle, Mauritius, and New Zealand fiber. Flax fiber, which is more like hemp than any other fiber, is used chiefly in textiles, but could be used very satisfactorily for certain twines, mats, shoe thread, *etc.*

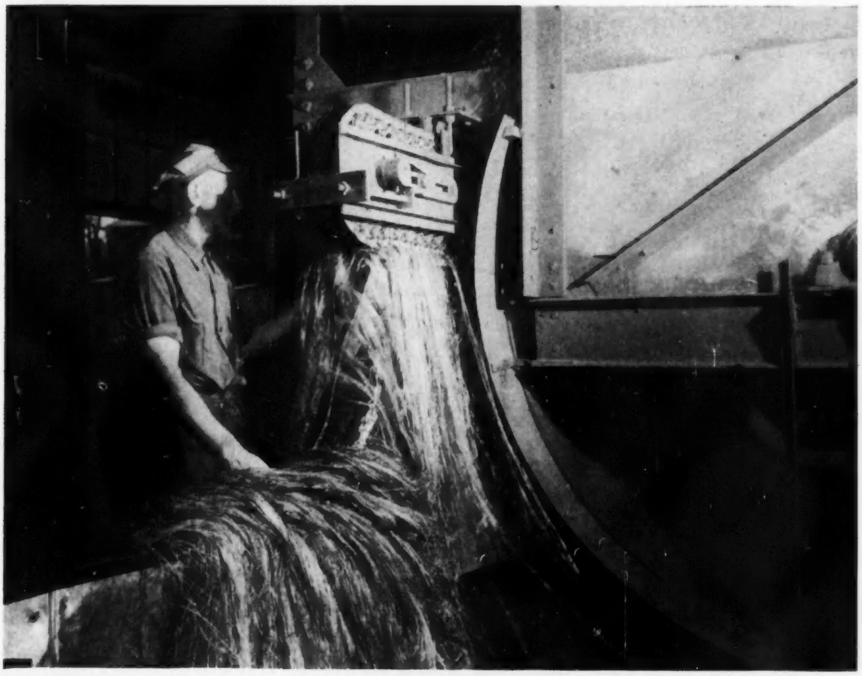


FIG. 5 (*Upper*). Hemp, after having been crushed in a break, being cleaned by beating and brushing in a scutcher.

FIG. 6 (*Lower*). Hemp fiber being hackled or combed after having been scutched, *i.e.*, cleaned of adhering woody parts. (*Photos courtesy U. S. Dept. Agr., by Forsythe*).

Hemp for marine cordage has been superseded by abacá (Manila fiber) because abacá ropes, cables and hawsers are lighter and will float in water, and this hard fiber is resistant to injury from salt water without being tarred.

Cotton, which is adapted to a wider range of uses than other vegetable fibers, has replaced hemp for many purposes, and in most cases advantageously, for it can be spun more easily and with less waste, making smoother and more uniform yarns. Cotton twines, of course, are not so strong or so durable as hemp twines of the same size or weight.

Jute, which was first brought from India to Europe and North America about a century ago, is now used more than all other vegetable fibers combined, except cotton. It is the cheapest, most plentiful and most easily spun of any of the soft fibers except cotton, and it is well adapted for purposes where strength and durability are of secondary importance. It is the weakest and least durable, however, of the important textile fibers. Jute has replaced hemp for many temporary uses, such as covering for cotton bales and packages of merchandise in transit and sacks for coffee, sugar and grain where the cheaper fiber may give as satisfactory service. The more short-lived jute does not give so satisfactory service as the stronger and more durable hemp for twines for tying heavy packages, hop vines that must be exposed to the weather all summer, and carpet warp or furniture webbing that should last many years.

United States Production and Consumption

In the middle of the 19th century, production of hemp in the United States reached a high of approximately 75,000 tons, decreasing until less than 1,000 tons were produced in prewar years. During the five-year period 1929–1933 an average of only 500 tons was produced, increasing to about 3,308 tons in 1941. Then, due to increased demands for all types of fibers, production rose during World War II to 6,216 tons in 1942, 62,803 in 1943 and 30,130 in 1944. Estimates of production in 1945 and 1946 were 2,232 and 1,715 tons, respectively.

From as early as 1881 until 1914 the annual consumption of hemp in the United States averaged around 11,000 tons, of which domestic production supplied about 6,000 tons. From 1916 to 1921 we produced an average of 9,000 tons annually, with the peak output of 18,000 tons in 1917. Imports amounted to 9,635 tons in 1917, bringing the total consumption for that war year to 27,635 tons. In the ten year period 1922–1931 the cultivation of hemp fiber declined very materially, the quantity averaging around 1,300 tons a year. Imports from 1922–1926, inclusive, averaged over 3,060 tons, and from 1927–1931 averaged a little less than 1,500 tons a year. The statistical record of acreage, yield, production, imports and apparent domestic consumption from 1931 to date, and a table showing acreage, yield and production by States are given in Tables I and II.

Production Costs

It cost Illinois farmers $21.19 a ton to produce and deliver hemp in 1943, according to R. H. Wilcox, associate professor of agricultural economics, University of Illinois, College of Agriculture. This was the average cost on 112 Illinois farms picked at random in the hemp-growing area of the State. The acre cost for hemp of $55.02 was about double the cost of producing corn. But a hemp yield of 2.6 tons an acre at an average price of $42.90 a ton made the crop profitable.

It took 19 man-hours an acre to produce and deliver an acre of hemp. This is about 10 hours more than is required in the production of an acre of corn, Mr. Wilcox reported. The tractor time aver-

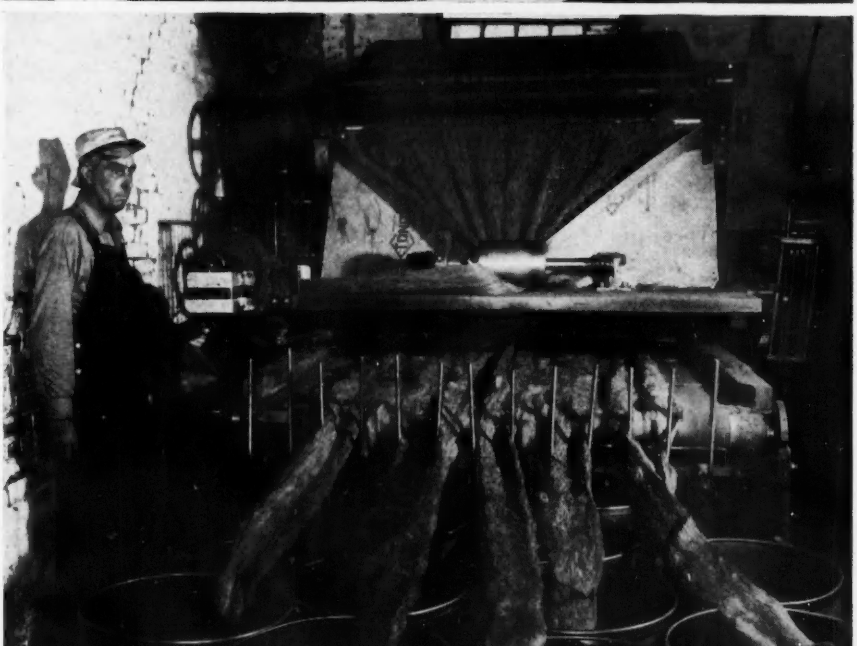


FIG. 7 (*Upper*). Long hackled fiber, twisted into hanks or hands.

FIG. 8 (*Lower*). Converting baled hemp into loose strands or slivers. (*Photos courtesy U. S. Dept. Agr., by Forsythe*).

aged five and three-quarters hours, approximately the same time used on an acre of corn. But hemp is a bulky crop and was grown over a rather large zone around each hemp mill in the State. As a result, 10 truck miles an acre were required to deliver the 2.6 tons produced.

The acre cost of $55.02 was made up of $23.21 for plowing the ground, preparing the seedbed, the cost of seed and sowing it; $10.89 for cutting, turning, binding and shocking; and $9.29 for loading and delivering. Seed cost the growers $12.52 an acre. Machines for cutting and binding the crop, which cost $5.00 an acre, were obtained on a rental basis through the local hemp mills.

The job that took the largest amount of man labor was loading and delivering, eight hours per acre. Next in order of labor demands were turning, three hours; shocking, two and one-half hours; gathering and binding, two hours.

Imports and Exports

In recent years hemp was imported almost entirely from Italy which ranked next to the Soviet Union as a world producer. The source of our imports in 1939, the last normal year before World War II, was as follows: Italy, 378 tons; Yugoslavia, 217 tons; Chile, 43 tons; all other countries, 40 tons; a total of 678 tons. Chile took over during the war years and supplied the bulk of our imports. (For total imports during recent years see, Table 1).

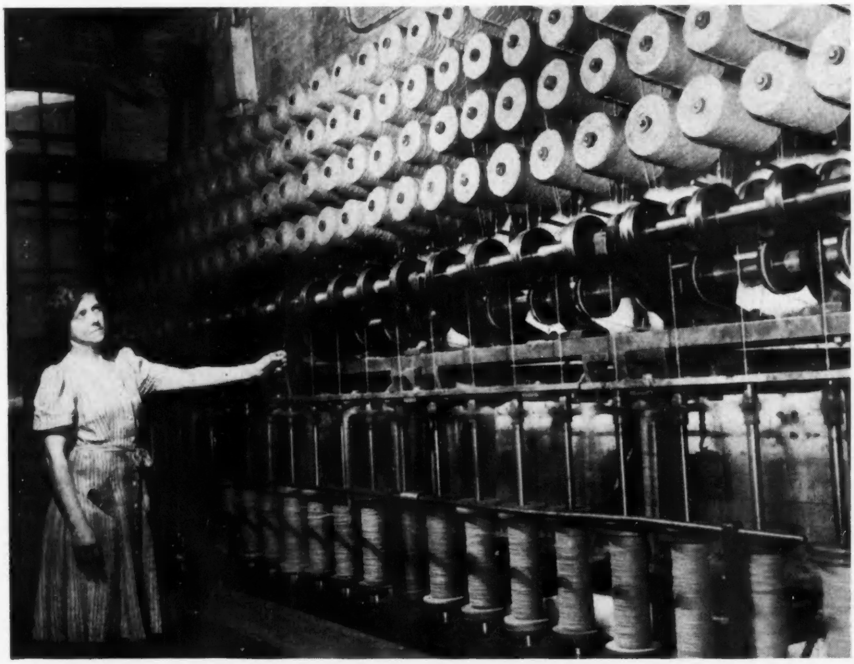
Exports of hemp were not separately recorded in official statistics up to 1943, but the amount was negligible. However, in 1943 and 1944 small amounts were recorded. Then during 1945 and 1946 the United States was afforded an excellent opportunity to dispose of the large stock of hemp on hand to war ridden

TABLE 1

HEMP FIBER: ACREAGE, YIELD, PRODUCTION, IMPORTS AND APPARENT CONSUMPTION IN THE UNITED STATES, 1931–1946

Year*	Acreage harvested*	Yield per acre*	Production	Imports	Apparent Consumption
	Acres	*Pounds*	*Long tons*	*Long tons*	*Long tons*
1931	320	850	122	1,018	1,140
1932	200	800	71	506	577
1933	140	750	47	630	677
1934	500	850	190	672	862
1935	700	875	273	927	1,200
1936	1,400	725	453	753	1,206
1937	1,300	800	465	778	1,243
1938	1,390	896	556	582	1,138
1939	1,440	890	572	678	1,250
1940	2,070	804	738	296	1,034
1941	7,400	1,001	3,308	1,195	4,503
1942	14,500	960	6,216	2,144	8,350
1943 †	146,200	962	62,803	336	63,185
1944 †	68,200	1,019	30,130	433	30,563
1945 ‡	6,500	800	2,232	45	2,277
1946 ‡	4,800	800	1,715	45	1,760

* Agricultural Statistics. 1945. (For years 1931 to 1944.)
† Preliminary—based largely on records of War Hemp Industries, Inc.
‡ Estimated.



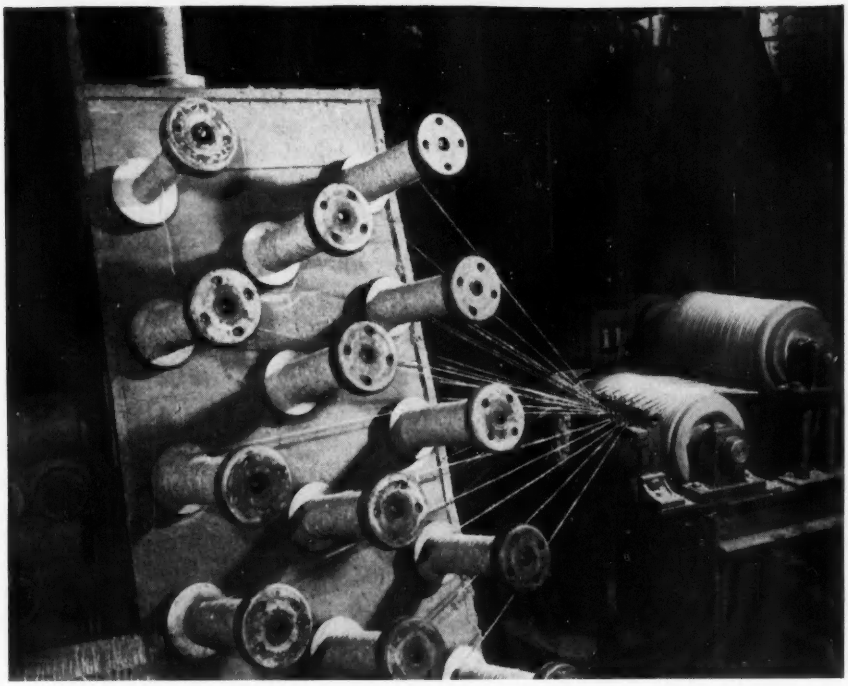


Fig. 9 (*Upper*). Hemp fibers being spun into twine.

Fig. 10. (*Lower*). Little strands of hemp being spun into larger strands. (*Photos courtesy U. S. Dept. Agr., by Forsythe*).

countries in need of this fiber. Consequently, 6,424 tons valued at $2,336,629 were exported in 1945. Of this amount, 4,843 tons went to France, 1,309 to Belgium, 272 to Canada. In 1946 a total of 6,828 tons were exported, valued at $3,062,838. France and Belgium again received the bulk of our shipments, amounting to 3,440 and 3,288 tons, respectively. In addition, 100 tons were shipped to Switzerland.

TABLE 2

HEMP FIBER: ACREAGE, YIELD AND PRODUCTION, BY STATES; AVERAGE, 1938–1942; ANNUAL, 1943 AND 1944

State	Acreage planted		Acreage harvested			Yield per harvested acre			Production		
	1943*	1944*	Average 1938–1942	1932*	1944*	Average 1938–1942	1943*	1944*	Average 1938–1942	1943*	1944*
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Pounds*	*Pounds*	*Pounds*	*Long tons*	*Long tons*	*Long tons*
Indiana	7,600			6,000			1,050			2,813	
Illinois	43,000	17,200		36,000	16,000		920	1,050		14,786	7,500
Wisconsin	32,000	22,000	3,200	30,000	21,000	916	1,060	1,090	1,392	14,196	10,219
Minnesota	46,000	13,500		30,000	11,000		830	900		11,116	4,420
Iowa	45,000	17,400		40,000	16,700		1,030	1,000		18,392	7,455
Kentucky	4,400	2,000	1,960	4,200	1,500	918	200	200	887	1,500	536
United States	178,000	72,100	5,360	146,200	66,200	910	962	1,019	2,279	62,803	30,130

Source: Agricultural Statistics, 1945.

* Preliminary: Based Largely on records of War Hemp Industries, Inc.

Note: See estimated United States acreage and production in table, Hemp Fiber: Acreage, yield, production, imports and apparent consumption, 1931–1946.

American Hemp Project During World War II

At the beginning of World War II it became apparent that a substitute must be found for abacá (Manila fiber), the supply of which was completely cut off. Practically the entire world's supply of this fiber emanated from the Philippines, with very small amounts coming from other areas in the Far East. It was a foregone conclusion that our supplies of sisal and henequen from the Netherlands East Indies, British East Africa, Mexico, Cuba and Haiti would become scarce as time went on, due to the necessity for our increased needs of cordage and binder twine. Then, too, we were faced with the fact that jute, of which about 98% is imported from British India, might become scarce because of any number of war conditions. Jute is used in the manufacture of burlap and cotton bagging, twines and rope, and many other minor items.

American hemp, therefore, was looked upon as the most satisfactory substitute that could be quickly produced in the United States for abacá, sisal and henequen fibers. Hemp is an annual crop which is planted in the spring, harvested in August and September, retted in September and October, and ready for processing in October or November. We did know that a fairly satisfactory rope could be made from hemp and so were willing

to take our chances rather than face a serious shortage of much needed rope. During 1942 an effort was made to produce as much hemp for seed as was possible. Arrangements were made for the planting of 36,000 acres in Kentucky, and some seed was planted to produce hemp for fiber by farmers in Kentucky, Wisconsin and Minnesota. However, even though a good crop of seed was harvested and shocked in Kentucky in 1942, bad weather set in before time for threshing, continuing until early spring, and it was impossible to thresh the hempseed. Large quantities were lost due to rain, snow or floods, and in early 1943 it was apparent that there would not be enough seed available to supply the 71 mills which had been planned for the project, so only 42 mills were decided upon, and the number was later reduced to 40. Even then some seed had to be imported from Chile so that all the mills could be operated. It was estimated at the beginning that the average cost per mill would be $290,000 but they actually cost around $350,000 each. A special division under the Commodity Credit Corporation of the United States Department of Agriculture was set up to operate the project. Money was supplied by the Defense Projects Corporation, leased to Commodity Credit Corporation, which contracted with the War Hemp Industries, a quasi-official organization, for the mills' operation. The harvests of 1943 and 1944 combined yielded 60,000,000 pounds of line fiber, sufficient for United States immediate needs. However, it became apparent that this project was for war needs only, intended to cover shortages, and as sisal and henequen supplies became available in larger quantities, it was decided to curtail the hemp project. Thus, the Commodity Credit Corporation was instructed not to arrange for plantings in 1945.

Since termination of the American hemp program negligible amounts of hemp fiber have been produced in the United States. However, recent research relative to the retting and scutching of hemp shows promise of considerable improvement in the processing qualities of hemp fiber, the outcome of which may materially affect the future possibilities of hemp in this and other countries.

Utilization Abstract

Bagasse. Bagasse is the residue from sugar-cane after the juice and sugar have been extracted. It "has found extensive use in the manufacture of insulating and other boards. Although numerous investigations have been made and plans projected for further use of bagasse, no other large scale use in the paper or paper board industry has been developed. The reason for this is that bagasse yields a pulp consisting roughly of half fibres and half pith cells. This pulp dries to a resistant sheet which does not easily deteriorate in water. By reason that the fibres and the pith differ greatly in physical characteristics, it is very easy to fractionate the bagasse into two fractions, one consisting of a fibrous pulp about equal in quality to hardwood soda [pulp]. The pith fraction, however (which can be collected on a vacuum filter) dries to a hard, horny mass and can be used only in admixture with other pulps for the purpose of imparting stiffness, *etc.*

"The crucial problem in connection with the further development of bagasse applications is that two mills would have to be built, one to utilize bagasse and canes to the best advantage and another to make a fibrous pulp, such as pine kraft, with which a percentage of the bagasse pith could be mixed to impart desired characteristics". (*Anon., Fibres 8(6): 195. 1947*).

A Troublesome Mold and Its Control in Gas-Purifying Sponge*

A certain mold-forming fungus, otherwise little known, has been found to be of economic importance by virtue of its peculiar ability to grow in the generally sterile and toxic sponge material used to purify illuminating gas.

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Introduction

In July, 1943, our attention was invited to an extensive growth of fungus in the gas-purifying sponge at the Everett, Massachusetts, plant of the Boston Consolidated Gas Company. The sponge employed in the removal of hydrogen sulfide from the gas is prepared by mixing 26 pounds of bauxite residue, a by-product obtained in the extraction of aluminum oxide from its ore, or ground bog ore, each essentially iron oxide, with each bushel of wood shavings. Each purifying box contains approximately 10,000 bushels of sponge.

Some of the badly fouled sponge was sealed by the fungus, thus partially obstructing the flow of gas. The fouling of the sponge was most extensive along the periphery of the top layer where the box is blanked for a width of about two feet to prevent the gas from by-passing between the edge of the box and the sponge. This area has no means of drainage and becomes very damp from condensed moisture draining from the sides of the box cover. Growth of the fungus was also abundant directly below the cross bars of the box cover. Here the sponge is moistened by water of condensation dripping from the cross bars above. The fungus subsequently grows over the entire sponge layer.

The Fungus and History

The fungus is characterized by dark colored cylindrical fascicles of hyphae crowned with dark conidial heads and creeping branching hyphae sporulating at the extremities. Short conidiophores bearing single apical conidia arise laterally along the hyphae. The conidia are one-celled, ovate to oblong to long pyriform, and faintly brown. On the authority of Dr. David Linder, the fungus was identified as *Sporocybe Borzinii* Goidanich (Stilbaceae) whose perfect stage is *Petriella Lindforsii* Curzi. The latter was not found. So far as we know, this is the first record of the occurrence of this fungus in the gas production industry.

In 1939 Lisi[1] reported on the control of fungi in gas-purifying sponge. The organisms involved in his studies were derived from fouled sponge, wood shavings and the atmosphere. None of them was sufficiently described to render recognition possible or to reveal its analogy to our particular fungus The difference appeared to be confirmed further by cor-

* Contribution No. 665 of the Massachusetts Agricultural Experiment Station.

[1] Lisi, A. G. Report on investigation on control of fungi in gas purifying sponge. Unpublished studies for Brewer and Gardner, Philadelphia, Penna., November 13, 1939.

FIG. 1. (*Upper*). An open sponge-box containing gas-purifying sponge of bauxite residue mixed with wood shavings and fouled by extensive growth of the mold *Sporocybe Borzinii*. FIG. 2 (*Lower*). Sample of fouled sponge, showing the compact whitish mycelial growth of the contaminating fungus.

respondence. Seil[2, 3] reported finding fungi in the dry purification boxes of several gas production plants in 1938 and 1939. These were submitted to entomologists and identified vaguely at different laboratories as *Mucor* sp., *Trichoderma* sp., *Graphium* sp., *Rhinotrichum repens*, *R. macrosporum* and *R. parietricum*. In another gas plant "fungi of the mushroom type" were found. Seil asserted that these fungi foraged in part on the sulfur in the gas flow and generated and returned hydrogen sulfide to the system. Adequate proof of this assertion is lacking. Also, from correspondence with Dr. Charles Thom, we learned that in 1938 and 1939 a *Graphium*-like fungus was a serious problem in dry box purification systems in gas production plants in Washington and Philadelphia.

Mycological literature reveals that the fungus *Sporocybe Borzinii* has been known previously in Europe as an inhabitant of cellulose in leaf mold in Scandinavia[4] and on wood pulp destined for paper manufacture in Italy[5, 6]. The source of the shavings used at Everett between 1937 and 1945 was northern New England, and a small amount came from southern mills. Our examination of the ore piles and recent introductions of wood shavings at Everett revealed the presence of different molds, but no mold corresponding to *Graphium* or *Sporocybe*.

The fungus is readily plated on artificial culture media by transfers of pieces of fouled sponge from freshly opened boxes. The absence of other organisms in the transfers revealed the unusual tolerance of this *Sporocybe* to the chemical components of the gas flow in the system. The fungus grows well on potato dextrose and corn meal agar, on broth of malt extract and on various species of wood, notably oak and maple. It makes scant growth on powdered bog ore and bauxite residue, but good growth on mixtures of these iron oxides with wood shavings. Growth of the fungus in all cases was featured by an abundance of spore production.

The gas used in the plant of the Boston Consolidated Gas Company is Coke Oven Gas. It is scrubbed for light oil and enters the plant with 225 to 250 grains of hydrogen sulfide per 100 cubic feet. All but 5 to 15 grains are removed with arsenic oxide and soda ash in their Thylox plant, and this small balance is removed from the gas flow in the iron oxide wood shavings sponge boxes. The analysis of the gas flow after it leaves the boxes is approximately as follows:

Carbon dioxide	1.8 %	Methane	25.9 %
Illuminants	3.4 %	Hydrogen	54.0 %
Oxygen	0.85%	Nitrogen	9.2 %
Carbon monoxide	5.2 %		
Hydrocyanic Acid Gas	0–6 grains per 100 cu. ft.		
Naphthalene	0–1 grain per 100 cu. ft.		

The specificity of the mold and its tolerance to such an unusual toxicant environment seemed remarkable. Molds had never been previously observed in the gas purifying sponge during the long history of gas production at Everett, in the opinion of the plant superintendent. During

2 Seil, G. F. Living organisms in gas purification. American Gas Association, Technical Section, Joint Conference, Production and Chemical Committee, New York City, May 20–22, 1940.

3 ———. Gas purifying material free from hydrogen sulfide generating organisms. United States Patent Office 2,213,615. September 3, 1940.

4 Lindfors, Th. Einige bemerkenswerte aus Kulturerde isolierte Pilze. Svensk Bot. Tidskr. **14**: 267–276. 1920.

5 Curzi, Mario. Petriella, nuove genere di Pirenomicete. Bull. Staz. Pat. Veg. Roma. **10**: 380–422. 1931.

6 Goidanich, G. Studi sulla microflora fungina della pasta di legno destinata alla fabbricazione della carta. Bull. Staz. Pat. Veg. Roma. **17**: 405–478, 1937; **18**: 461–467 1938. Also, La Microflora della Pasta-Legno. Sporocybe Fr. pp. 172–177. E. Staz. di Pat. Veg. Roma. Ente Nazionale per La Cellulosa e per La Carta Roma 1938.

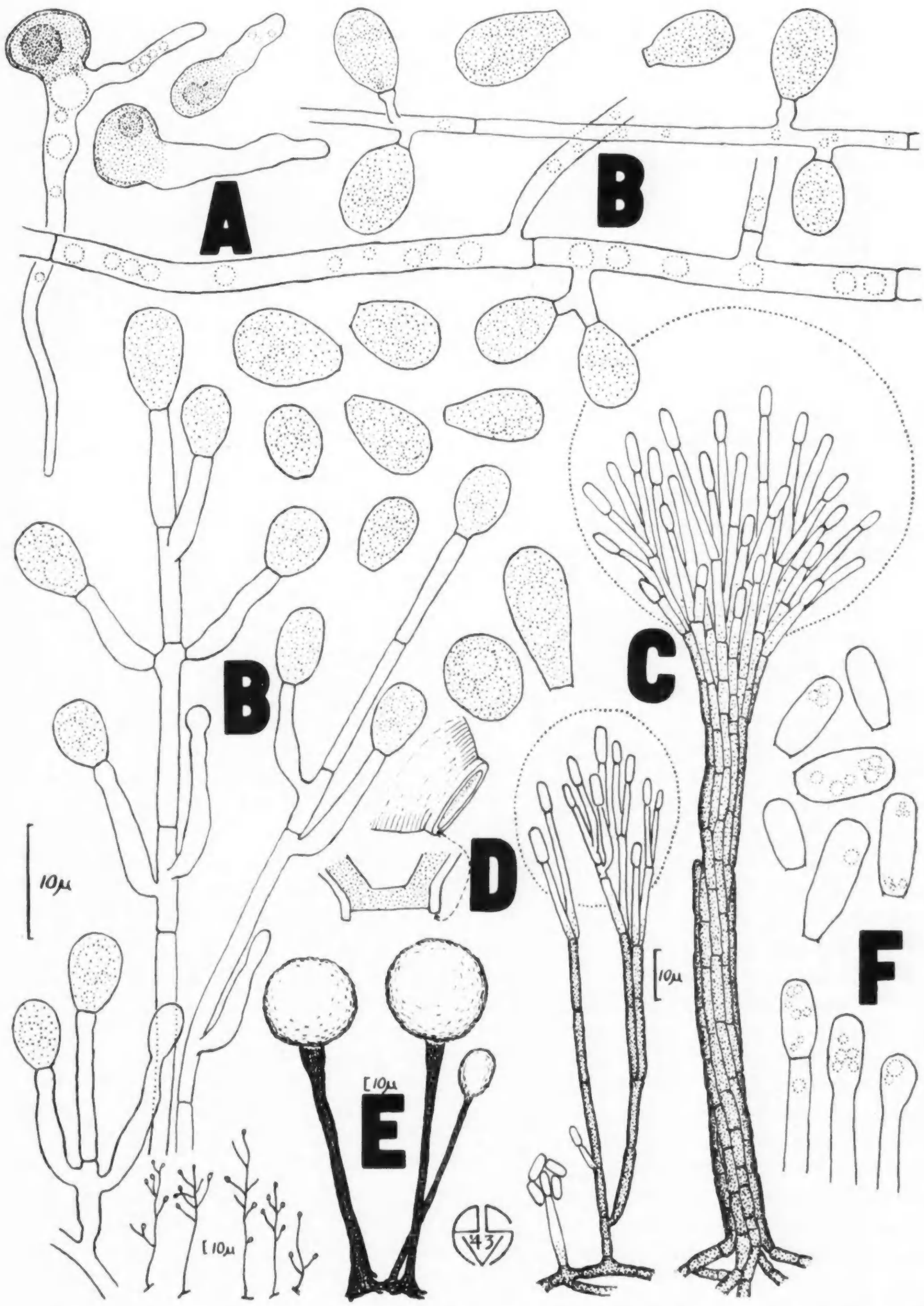

FIG. 3. Microscopic representation of *Sporocybe Borzinii* Goidanich. A, germinating conidia. B, creeping fertile hyphae, showing conidiophores and origin and arrangement of the conidia. C, synnemata (fascicles of fertile hyphae) bearing conidia at apex in a head. D, sectional and contour views of base of spore showing outer and inner walls. E, habit, sketch of synnemata with heads. F, development and septation of conidia at apex of synnema.

the course of these studies (1943 to 1944) 16 gas-purifying boxes were in use, of which 14 were fouled by *Sporocybe*.

Control in the Gas Plant

To effectively prevent the introduction of molds into the gas plant, Seil[3] offered an invention that involves the addition of a phenol disinfectant, such as tar acid, to the iron oxide, wood shavings or mixture of the two before making up the dry sponge boxes. The treatment of the wood shavings or prepared sponge with other chemical disinfectants or with lethal temperatures considered in our studies should also be satisfactory. In the gas plant the installation of adequate facilities for the drainage of water in the design of the purification boxes should also contribute to a partial solution of the problem.

Alkaline Reaction. For many years the purifying sponge at Everett was made with bauxite residue, a by-product obtained in the extraction of aluminum oxide from its ore. The alkalinity of the residue is reported to be upwards of pH 10. More recently and coincident with the prevalence of *Sporocybe Borzinii* in the dry purification system at Everett, the sponge has been made with powdered bog ore having an acid reaction in a range of 5.5 to 6.5. The reaction is rendered alkaline in the preparation of the sponge by adding soda ash or lime or both. An alkaline reaction is highly desirable in the removal of hydrogen sulfide from the gas flow.

The fungus grew well on sponge of powdered bog ore and pine wood shavings reading pH 4.5, and on pine wood shavings alone. Its growth was relatively poor on sponge of bauxite residue, pine wood shavings, and lime reading pH 9.0, and excellent on sponge in a freshly opened box reading pH 8.2. Growth is excellent in aqueous malt extract in a range of pH 4.9–7.2.

A 0.2 percent aqueous broth of Difco corn meal agar was made up in 100 cc. quantities and treated with increasing amounts of an aqueous solution of sodium hydroxide to give a series of ascending pH readings. After autoclaving, inoculum of *Sporocybe* was added to each flask. Details of the experiment and the comparative growth of the fungus are shown in Table 1.

TABLE 1

RELATION OF INCREASING ALKALINITY TO THE GROWTH OF SPOROCYBE IN NUTRIENT BROTH

Flask	Reaction of Broth		Amount of growth
	Before inoculation	After incubation	
A*	pH 7.2	pH 7.0	++++++++
B	7.8	7.2	++++++
C	7.8	7.7	+++++
D	8.8	8.4	++++
E	8.5	8.5	++++
F	8.9	8.9	++
G	9.3	9.2	+
H	9.8	9.8	0
I	10.3	10.3	0

* Not treated with sodium hydroxide.

The best growth was shown at pH 7.0–7.2. Growth decreased to zero as the alkalinity increased to pH 9.8 and with corresponding increases of sodium hydroxide. Lisi reported that the growth of his molds stopped at pH 10–11, indicating that the maintenance of a highly alkaline reaction in the sponge might solve the problem of molding. Lisi found that ammonia added to the gas stream was repressive to the molds, and suggested the addition of 12 grains of ammonia to each 100 cubic feet of the gas flow to maintain the alkaline reserve of the sponge.

Heat. The thermal death point of the fungus was determined for intervals of one to 15 minutes by immersing culture tubes of the fungus in water maintained at fixed temperatures and then subculturing. The results of several trials are summarized in Table 2.

On the basis of these studies the treatment of the wood shavings or the prepared sponge with heat at lethal temperatures would appear to be an effective means of eradicating the fungus. The effectiveness of heating can be impaired by inadequate penetration or distribution of steam. The application of heat to the sponge *in situ* introduces the factor of injury to the cast iron purification structure. Lisi reported that mixed fungi in wood shavings were killed at 158° F. maintained for at least six hours, and a period of six hours of steaming after proper heat distribution had been obtained was recommended.

TABLE 2

THERMAL DEATH POINT OF SPOROCYBE

Time (minutes)	Temperature (degree Fahrenheit)						
	130°	140°	150°	160°	170°	180°	190°
1	–	–	–	–	–	+	+
5	–	–	–	+	+	+	+
10	–	–	+	+	+	+	+
15	–	–	+	+	+	+	+

\+ Lethal.
– Not lethal.

Formaldehyde. The lethal action of formaldehyde was determined by exposing cultures of the *Sporocybe* fungus for 24-hour periods to a measured volume of atmosphere containing known amounts of 37 percent formaldehyde. A lethal effect was obtained with 3.75 cc. formaldehyde per cubic foot of space. The boxes at Everett have a gross volume of almost 13,000 cubic feet. Because of a possible discrepancy between laboratory and industrial conditions, practical application at the rate of 7.5 cc. per cubic foot of gross volume, or almost twice the lethal amount of laboratory determination, was recommended.

The inlet and outlet valves to the boxes at Everett were closed. Formaldehyde, diluted 1 : 3 parts with water, was injected by steam syphon into the inlet of the box. In other instances the diluted formaldehyde was steam-syphoned through the steam manifold in the middle of one side which carried the formaldehyde between successive layers of sponge. Culture tubes loosely plugged with cotton were spaced in a continuous line across the top layer, approximately 30 inches apart, where they remained for 16 to 48 hours while the box was idle and closed. No higher than 77 percent of the cultures were killed in these experiments. The fungus was also recovered by isolations directly from samples of the sponge. Solutions of formaldehyde injected into the system from the outside did not reach the fouled sponge layers and were no better than steam injections.

In subsequent tests the drenching of the fouled top layer of sponge with 1–50 formaldehyde solution at the rate of one gallon per square foot, after forking over and breaking up the surface, has controlled the fungus. Use of the chemical in this manner is both economical and practical.

Sodium Pentachlorophenate*. Exploratory studies on the action of sodium pentachlorophenate were made, since the chemical was considered the best of many disinfectants studied by Lisi for controlling molds in the gas-purifying sponge. Aqueous broth of Difco corn meal agar was poured into flasks in 100 cc. quantities, and a water solution of the chemical was added to give a range of dilutions of 0.002 to 0.1 percent. The flasks were autoclaved and subsequently inoculated with pieces of wood bearing the *Sporocybe* fungus. No growth of the fungus occurred in the stated range of dilution. Excellent growth occurred in the untreated flasks. The experiment was re-

* As "Santobrite", containing 78.6% sodium pentachlorophenate and 11.4% sodium tetrachlorophenate; Monsanto Chemical Company, St. Louis, Missouri.

peated, using an aqueous 1 percent malt broth, except that the chemical was withheld eight days or until the fungus had made a good growth, then added to give a series of dilutions from 1–500 to 1–1,000,000. After further incubation, subcultures were made from the flasks, having a range from 1–500 to 1–5,000 or 0.2 to 0.05 percent of chemical mixture. No growth occurred, indicating a lethal effect. Lisi recognized a 0.1 percent solution as the minimum lethal concentration, and 0.2 percent for experimental practical application.

Sodium pentachlorophenate mixture was added to 100 cc. quantities of a nutrient broth of corn meal and malt extract to give a series of concentrations from 0.00005 to 0.5 percent. None of the flasks was autoclaved. Inoculum of *Sporocybe* on wood shavings was added to each flask. All of the flasks except those with a concentration of 0.00005 percent of the chemical and the untreated flasks remained sterile. The lethal action of sodium pentachlorophenate mixture at extremely low concentrations is striking. Use of the chemical at Everett gave satisfactory control.

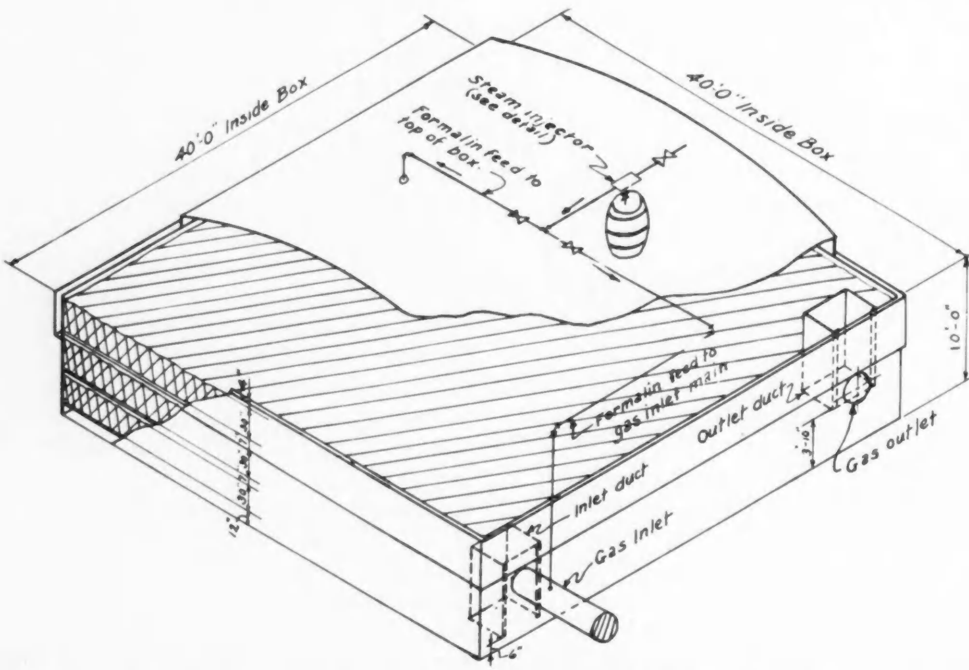

FIG. 4. Gas purification box showing details of construction and method of applying formaldehyde. Boston Consolidated Gas Company, Everett, Massachusetts. Drawn by B. M. W.

Summary

A phaeo-stilbaceous mold, *Sporocybe Borzinii* Goidanich, is a frequent cause of the fouling of the gas-purifying sponge comprised of iron oxide and wood shavings in the gas production industry.

Adequate drainage conditions in the purification boxes to remove water of condensation is a partial control measure.

Temperatures of 180° F. for one minute, or 150° F. for 15 minutes, intimately applied to the fungus are lethal. Sterilization of the wood shavings or the prepared sponge with heat is recommended.

An initial highly alkaline reserve in the sponge and the maintenance of alka-

linity upwards of pH 10.0 with lime or soda ash arrest the growth of the fungus.

The injection or diffusion of formaldehyde into the purification boxes by steam syphon is recommended for trial. Wetting down the top layer of sponge with 37 percent formaldehyde diluted 1–50 with water, or with 0.2 percent solution of sodium pentachlorophenate mixture gave satisfactory control of the mold.

The reaction of the fungus to the various components of the gas flow would make an interesting subject for study, and might suggest other means of control.

Utilization Abstract

Rubber in Ceará. In the State of Ceará, near the eastern extremity of Brazil, wild trees of *Hancornia speciosa* Gomes and of *Manihot Glaziovii* Muell.-Arg. are the principal rubber-producing trees. There are also some small plantings of *Manihot* and a few isolated trees of *Castilla elastica* Cerv., another source of rubber, as well as two small plantings of *Hevea* in the damp mountains. During the recent war rubber was produced from *Hevea* plantings under Japanese control and were exported in German ships to be sunk by American planes and boats. Salvaging the floating rubber near the coast became very remunerative for native fishermen.

The genus *Hancornia,* with many species and varieties, occurs from Paraguay and Bolivia through the states of Matto Grosso, São Paulo, Goiaz and Minas Gerais to Ceará, Piauí, Maranhão and Pará in Brazil. *H. speciosa,* which seems to be the source of most material obtained under the name "mangabeira", is found in small areas along the sandy coast, on high sandy chapada or wooded savanna of the Serra de Araripe and in one small isolated colony in the Serra de Ibiapaba near Campo Grande.

The trees are tapped usually three times annually by the poor and primitive natives using small knives to make deep V-notches, and cups to catch the exuding latex. The cups are made of folded, tough, leathery araticum leaves (*Annona coriacea* Mart.) and are fastened to the trees by thorns or other primitive means. Coagulation is effected by heating the pure latex in a bowl over a fire, adding salt or alum; or by adding an equal amount of warm water to the latex and then a small amount of table salt solution. The coagulum, about an inch thick, is then rolled into sheets on a board. There are modifications of these tapping and coagulating methods, but the natives are generally very reluctant to adopt any improvements in the operations. According to "one good native recipe for coating cotton cloth a tablespoon of powdered sulfur and the white of an egg are mixed with a large cup of water added to a liter of pure latex and spread thinly over the fabric. When dry this is placed in the sun for a day to cure".

The large genus *Manihot* centers in Brazil, from Ceará to central Bia. One species, *M. esculenta* Crantz, is the source of tapioca and is extensively cultivated in the East Indies. *M. Glaziovii,* known as "manisoba", is native to the Serras de Baturité and de Maranguape in Ceará, and has been tried on plantations in Africa and the East only to be replaced there by *Hevea.*

Tapping is conducted by the natives in a variety of ways, either from the trunk where the latex is collected in attached cups, or from the base or roots of the tree where the latex collects in a small hole dug into the ground and lined with pounded and sifted calcareous clay. Coagulated dry latex collected in strings or globules from hackings on the trunk are known as "choro", *i.e.,* "tears", and as "sernamby"; that coagulated in the powder-lined ground holes as "chapa".

Both manisoba and mangabeira rubber, even after washing, cleansing and rolling in factories set up for the purpose, are inferior to *Hevea* rubber as yet. They do have some industrial use, however, and there are exports of the material.

Manisoba seeds are being planted along with other crops by many property owners, and the young trees can be tapped after two years. (*H. C. Cutler, Bot. Mus. Lfts., Harvard Univ. 12(9): 301. 1946*).

Plants Useful For Bee Pasture

White, sweet, alsike and red clovers and alfalfa are the principal sources of surplus honey in northern United States, from the Atlantic to the Pacific. Buckwheat and heartsease are secondary and autumnal sources.

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Introduction

RECENT changes in agriculture have brought the honeybee prominently to public attention. It is the only insect useful for pollination whose numbers can be controlled. Until recently there was no consciousness of a pollination problem, for with more than 200 species of wild bees ranging in size from half the size of a housefly to the bumblebee, there were pollen distributors for all plants. With more intensive cultivation, however, the nesting sites of bees have been destroyed, and the use of poison to control insect pests has killed the wild bees until, in many neighborhoods, the situation is serious. The United States Department of Agriculture has issued a bulletin, "The Dependence of Agriculture upon the Honeybee", which lists 50 crops that depend wholly or in part upon the honeybee for pollination.

In recent years honey production, along with other farm activities, has become highly specialized. Some beekeepers number their colonies by thousands, while in other neighborhoods few honeybees remain. The present acute pollination problem requires better distribution of the bees. Prof. J. N. Martin of Iowa State College of Agriculture estimates that to insure success of the soil conservation program it will be necessary to add a million colonies of bees in Iowa alone.

The prosperity of the beekeeper thus becomes of vital public interest. Until recently little attention has been given to planting for bee pasture. The beekeeper has moved his bees to neighborhoods where nectar-yielding plants were growing, and made the most of the harvest. For the greater part commercial honey comes from a few plants which are grown in large acreage. The minor sources, however, are of great importance also, since the bees must find support through the entire year. In localities where the bee pasture is confined to a few plants, there is often a severe dearth at times when these are not in bloom. With a shortage of nectar and pollen coming fresh from the field, the bees conserve their stores and restrict brood rearing. As a result, the colony population declines rapidly and the bees may be in poor condition for the honey harvest or may lack sufficient numbers to effect the desired pollination of plants dependent upon them for that service.

While the public has long regarded the honeybee as of value solely as the source of nature's best sweet, recent investigators have placed a much higher value on her services in pollination. It is now realized that the honeybee brings a much higher return to the owner of the plants she visits than to her owner who gets the honey. This service has been estimated at from ten to fifty times the value of the surplus honey which goes to market. In

circular E-584 of the U. S. Department of Agriculture it is stated: "Few realize that, although the beekeeping industry produces in excess of 200 million pounds of honey and four million pounds of beeswax annually, these are merely by-products, and its principal role is in the pollination of the many agricultural crops for the production of seed and fruit".

To insure the presence of a sufficient number of honeybees to provide for pollination, it is necessary that an ample supply of nectar and pollen be available throughout the season. While the main honey crop is often gathered within a few weeks time, there is need of sustaining forage from early spring until late fall.

Problems of Location

The beekeeper who is seeking a location for a large outfit must make a very careful survey of the flora within a radius of two to three miles of the site of each of his apiaries. He must know first whether there is a sufficient acreage of a major crop to provide a worthwhile harvest. He must know which plants flower before and after the main harvest, the extent of their support and the competition offered by other insects for the available nectar.

There is great variation in the quality of honey from different plants, and a comparable variation in the price which the product will command in the market. Honey from the clovers is light in color, mild in flavor and in heavy demand. Honey from buckwheat is very dark in color and strong in flavor, and the demand is limited to special uses and to a trade long familiar with its peculiar qualities. Honey from some plants has flavor of such disagreeable quality as to find little or no demand in the market. Such honey must be separated from the marketable product and fed back to the bees.

The time when the main honeyflow occurs is also of great importance. It is very difficult to build up colony strength to the point where full advantage can be taken of a heavy honeyflow that comes very early in spring. The ideal location is one with a great variety of plants blooming through the entire season and with at least two major sources of surplus honey which bloom at different times. In such a location honey production is a very satisfactory source of livelihood. There it is safe to say that a beekeeper with 500 hives will enjoy an average income equal to that of a farm of 160 acres, and with a smaller investment. At the same time, the larger his net return the greater the income of neighboring farmers is likely to be because of the presence of his bees among the flowers.

While the beekeeper is interested in the honey, the bee is equally interested in pollen. Pollen is very important in the food of young bees, and without it the larvae fail to develop. Plants which yield pollen at a critical season thus assume special importance, since they insure the prosperity of the colony. There are a few localities where heavy yields of honey are secured which offer serious problems for the beekeeper because of the shortage of pollen at other seasons. Along the Appalachicola River in Florida, for instance, the tupelo yields nectar abundantly, and one local beekeeper has harvested as high as 250 barrels of honey in one season, but after the tupelo is finished blooming there is so little for the bees for a long period that many beekeepers move their bees away for several months.

Migratory beekeeping has become quite general in many localities since the automobile has provided easy means of moving long distances. Such moves often make it possible for the beekeeper to take advantage of a honeyflow from another source when his crop is over.

An important factor in the attraction

FIG. 1 (*Upper*). Smooth sumac, *Rhus glabra*. FIG. 2 (*Lower*). Flower and fruit of tulip tree, *Liriodendron tulipifera*. (*Photos courtesy New York Botanical Garden*).

of flowers to bees is the sugar concentration in the nectar. Dr. O. W. Park of Iowa State College was a pioneer in the study of this relation, and he it was who developed the practice of measuring the contents of the honeysac of the bee by use of the refractometer. Since bees are constant in their attention to a particular plant while it continues to yield, and do not visit different kinds of plants on the same trip, it is necessary only to catch the bees on the flowers which one wishes to study.

The sugar concentration in different plants varies greatly and explains why bees may visit the flowers of one plant while neglecting others. The greater the concentration of sugar in the nectar, the less labor will be necessary on the part of the bees to evaporate the excess moisture when storing the honey. Since this concentration varies from a low of 4% in some varieties of pear to high of 50% to 60% in some species of hyssop (*Agastache* sp.), it is not surprising that the bees favor some plants above others. It also explains why they will often fly over the bloom on some varieties of fruit to visit others at a greater distance from the hive.

Some plants are rather dependable for their yield of nectar nearly every season, while others yield only on rare occasions. Just which factors control the secretion of nectar are not fully understood. In some cases the kind of soil seems to be the most important, but there is great variation from time to time under what appear to be the same conditions. Weather certainly is very important, but there very evidently are other influences which are not yet explained.

The beekeeper has learned to expect but little honey from buckwheat on heavy soils; it yields best on light or sandy soils. He seldom gets honey from cotton on sandy soils, but heavy yields on rich black lands. With such information as he has, the beekeeper seeks a location where there is a large acreage of plants generally recognized as the source of surplus honey. Thus in the northern

States his dependance is likely to be placed on the legumes commonly grown as farm crops. The clovers, of the genera *Trifolium* and *Melilotus*, and alfalfa (*Medicago sativa* L.) are the sources of the greater part of the honey produced commercially from New England to the North Pacific Coast. There are limited areas where other plants may be important locally, as the tulip-tree (*Liriodendron tulipifera* L.) in Maryland, wild raspberry (*Rubus Idaeus* L. var *strigosus*) in Michigan, and basswood (*Tilia glabra* Vent. = *T. americana* L.) in Wisconsin, but they provide only a small part of the surplus which goes to market.

Early Spring Honeyflow

Over a wide expanse of territory the first nectar and pollen in spring comes from one of the maples. The soft maple (*Acer rubrum* L.) blooms so early that it is a rare season when heavy freezing fails to follow its first opening. With a few warm days the bees get a big lift, and it often happens that there will be a gain in weight in the hives while there is still snow on the ground. Too often the weather is so cold and wet that the bees have little chance to fly during its flowering, and a rich source of nectar is lost because of unfavorable weather. In the Northwest the big-leaf, or Oregon, maple (*Acer macrophyllum* Pursh) also blooms early, and the beemen usually report disappointment because its yield is cut short by rain.

Mountain maple (*Acer spicatum* Lam.) blooms much later, and the beekeepers usually profit from its presence. This species is generally found as an under shrub in the shade of larger trees in Michigan and New York, and its range is limited to a relatively small area.

Like the maples, the willows, (*Salix* sp.) also bloom very early, and the flowering of the pussy willow is one of

FIG. 3 (*Upper*). A new clover from Russia, *Trifolium ambiguum*.

FIG. 4 (*Lower*). The deep, spreading, underground roots of *T. ambiguum*.

the first signs of spring. Willows yield nectar generously, and with favorable weather good crops of honey can be expected from them. Farther south, where they are of less importance, some species bloom much later. In Saskatchewan the Bebbs willow (*S. Bebbiana*) flowers in May when weather is likely to be more favorable, and the bees accordingly profit. Speaking generally, willows bloom too early to be dependable, and it is only in an unusual season that the bees get maximum benefit. When weather permits, the profit is substantial. One prominent Iowa beekeeper reports that he has harvested only one crop from willow in 23 years when, with several days of still warm weather and the willows in bloom, a strong colony of bees gathered about 30 pounds of white honey of mild flavor.

Dandelions come into bloom after maples and willows, they cover a wide expanse of territory and they are listed among the important honey plants in nearly all parts of the nation and Canada. They yield nectar very abundantly, and, although the season is so early that colony strength of the bees is usually too low to permit full advantage, at times there is surplus honey from this source. The honey is dark in color and of pronounced flavor, but not enough of it goes to market to make much difference. The value of dandelion is principally for colony support and is worth millions of dollars to the beekeeping industry for this reason. While the dandelion is regarded as a weed, it is seldom a source of annoyance except on lawns. In pastures it apparently is of some value for forage as well as for honey, and on the whole, can be regarded favorably.

The Major Honeyflow

The early blooming plants serve the beekeeper primarily for building up colony populations to the point where the bees are strong enough to store a substantial harvest for the main sources. When white Dutch clover (*Trifolium repens* L.) opens its flowers in late May or early June, the honey harvest really begins over an immense scope of country. For many years this plant was the main source of honey going to market from New England to the Missouri River and south to the Ohio. Of late, sweet-clover (*Melilotus*) has been contending quite successfully for first place. White clover is present everywhere in lawns and pastures and along roadsides in


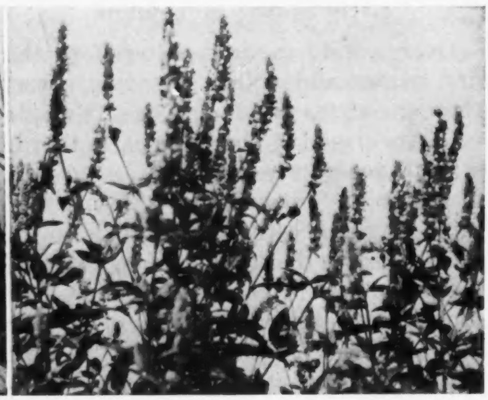

FIG. 5 (*Left*). Chives, *Allium Schoenoprasum*, is attractive to bees.
FIG. 6 (*Right*). Anise hyssop, *Agastache Foeniculum*, attracts bees in all kinds of weather and over long periods.

seasons of normal rainfall. It is a shallow rooting plant which spreads rapidly from runners in moist weather and suffers severely from drought.

At times the nectar yield is very heavy, and strong colonies of bees make a net gain of several pounds daily. The plant is sensitive to weather conditions, and the honey flow often stops suddenly due to weather changes. It is cut short most frequently by dry weather. The flow increases in intensity northward, and crops are substantially larger from white clover in Minnesota than in Louisiana. In seasons of ample moisture, the honey crop from this source is fairly dependable from central Iowa northward, but far more uncertain southward. White clover is abundant on the rich soils of the lower Mississippi River delta but yields good crops of honey only infrequently, while offering a rather dependable harvest in northern areas. The flowering season for white clover is long, depending upon the available moisture. In wet seasons it blooms from late May until August or September, and it is in such years that the beekeeper profits most.

While alsike clover (*T. hybridum* L.) will grow nearly everywhere that other clovers thrive, it is known principally from Minnesota, Wisconsin, Michigan, Ontario and New York. In those regions it yields heavy crops of light colored honey and is especially valuable to the beekeeper. The mild flavored honey is regarded highly for table use. During a good honeyflow strong colonies will store from ten to 20 pounds daily for brief periods of time.

FIG. 7. *Sabal palmetto*, a source of nectar in Florida.

Red clover (*T. pratense,* L.) is the most popular legume among the farmers of the Mid-West, but the corolla tubes of the flowers are too deep to permit the bees to reach the nectar readily. They do, however, get some nectar from the plants at times and often visit the flowers for pollen. Extension Bulletin 253 of The Ohio State University claims that red clover blossoms are 82% pollinated by honeybees. For this reason there is an insistent demand for more bees in the clover seed-producing areas.

Because of the difficulty in getting the nectar, the bees often neglect the red clover blossoms when other flowers are open. Dr. Joseph Zofska of Prague spent many years in an effort to develop a red clover with a short corolla tube. He was fairly successful, and the writer had a small field of this Zofska clover grown from seed received directly from the originator. The bees visited the flowers freely and harvested the honey successfully, but the plants were winter-killed and the planting lost for lack of winter hardiness. An effort has been made at the Iowa Agricultural Experiment Station to cross the Zofska clover with acclimated red clover to obtain a hardy strain with short corollas.

FIG. 8. Marjoram, *Origanum vulgare,* escaped from gardens and established in some eastern localities, is the source of a good honey.

For 50 years beekeepers argued with farmers that sweet clover (*Melilotus alba,* Desr.) was a good forage plant. The farmers regarded it as weed and even went so far as to get laws passed requiring its eradication. The plant finally won recognition during the first World War. The grain fields of the Northwest were at that time showing

signs of failing soil fertility, with no available legume suited to the region. Sweet clover proved to be a good soil builder and well adapted to the climate. The urgent demand for wheat resulted in the adoption of sweet clover in the rotation of the Red River Valley of North Dakota, and it soon spread rapidly. It was even accepted in the corn belt where red clover had so long been the most popular legume. The drought years of the 1930's, when red clover and alfalfa plantings failed for lack of moisture while the sweet clover survived, helped to establish the latter. Farmers provided with it found pasture for their cattle, while their neighbors were forced to furnish dry feed for lack of it.

With the spread of sweet clover came a corresponding expansion of commercial honey production. Soon honey by carloads was shipped from North Dakota, and beemen who had operated a hundred colonies wanted a thousand. Thousand-colony outfits became common, and production of 100,000 pounds of honey in a season was no longer a novelty.

In the climate of the Missouri River Valley and northward sweet clover is at its best. The hot days and cool nights, with rich soil and sufficient moisture, stimulate nectar production to a surprising extent. A hive on scales in the writer's apiary in 1945 made a net gain of 549 pounds from June until September. Of this, 449 pounds were removed as surplus, leaving 100 pounds to carry the bees until the following spring when dandelion would again come into bloom.

Of late, sweet clover has become so widely planted that there is probably more honey going to market from this source than from any other. It is light-colored, of mild flavor and commands a ready sale at a good price.

Alfalfa (*Medicago sativa* L.) is the most important forage crop west of the Missouri River and is the source of a large part of the surplus honey produced in that region. It is at its best in the irrigated regions of the Rocky Mountains, although quite generally cultivated also on the farms to both the east and the west. It is erratic in its nectar secretion east of the Mississippi River, and yields honey only at uncertain periods. In the east the nectar yield usually comes when the weather turns dry after a spell of wet weather when the soil is saturated with water. At such times the plants find conditions similar to those of the irrigated west, with the air warm and dry and roots well supplied with moisture. The quality of alfalfa honey varies greatly with environment. It is best in the high altitudes of Idaho and surrounding areas. There the color is very light and the flavor mild. In the Imperial Valley of California the flavor is strong and the color dark. Altitude as well as soil and weather appears to be an important factor.

Honey from Fruit Bloom

While most fruits bloom early and thus yield less honey than would be stored at a later season, substantial crops, nevertheless, are gathered from orchards. The best known in this class comes from the orange, and in California orange trees constitute one of the most important sources of surplus. The honey is of light color, good though pronounced flavor, and commands a premium in the market. Since the principal honeyflow from orange comes in April, it requires good beekeeping to get the big crops which are possible. The nectar yield is very heavy, and at times men working among the trees find their clothes saturated with it. Good orange locations are in demand, and beekeepers often move their bees long distances to harvest the crop. While there is a scattering of flowers over a long period, the main honeyflow from this source usually lasts about three weeks. Yields of from 100 to 200

pounds per hive are not unusual under favorable conditions.

Surplus honey from apples is rather unusual because of the early flowering. Few colonies of bees are strong enough to store substantial surplus, and weather conditions often are unfavorable. The nectar yield is abundant, and the sugar concentration high. Given good weather, strong colonies readily store surplus from this source, and much larger yields would be possible if all nectar could be gathered.

Although pear orchards of large extent are common in some localities, we hear nothing of pear honey. Bees visit the flowers freely, but, it appears, mostly for pollen. The nectar yield is at times abundant, but the sugar concentration is so low that little remains after the moisture has been evaporated. Orchardists complain that bees brought in for pollination too often neglect pear blossoms in favor of those with higher sugar content in the nectar.

Cherries, plums, apricots and peaches all yield nectar freely and are much visited by bees, but apparently the nectar is consumed in colony support and is rarely stored as surplus.

FIG. 9. Meadow sage, *Salvia pratensis*, offers much promise for bee pasture.

The raspberry blooms somewhat later than most orchard fruits, and substantial crops of honey are stored from wild plants in areas where there is large acreage. Raspberry honey is especially well known in Michigan and Ontario, and some surplus is reported from cultivated bushes in Oregon where large acreage is

devoted to their cultivation. The honey is of fine quality and in good demand, although not enough is produced to be well known.

The blackberry is known as a source of honey especially in the South where wild plants are abundant in every fence corner and waste area. The honey is not equal to that of raspberry in quality, nor is it produced in large quantity.

Fall Honeyflow

In a good beekeeping location there will be a second surplus honeyflow at some time during the season. In large areas of the northeastern States this second flow comes in late summer from buckwheat or from one of the smartweeds commonly known by the beekeepers as "heartsease".

Buckwheat (*Fagopyrum esculentum* Moench) is important as a source of honey principally on light sandy soils of New England southward to Pennsylvania and in the region of the Great Lakes westward to Michigan. Little honey is harvested from it on the rich soils of the Mississippi Valley or the hot and dry Plains Region. Conditions which insure optimum yields of nectar from buckwheat are just the opposite of those required by sweet clover. Sweet clover makes a poor showing in the buckwheat region as compared to its behavior in the upper Missouri River Valley. Likewise buckwheat is a disappointment in the western area. Given a sandy soil tending toward acidity with ample moisture in a humid climate, buckwheat can be expected to yield satisfactory crops of honey. There are few other locations which will support as many bees in one spot as have been kept in some neighborhoods in New York where buckwheat is an important farm crop. At one time, the late E. W. Alexander kept 700 hives of bees in one apiary at Delanson, New York. Large apiaries were the rule in that neighborhood in contrast to some southern regions where 30 or 40 colonies were as many as could find support within flying distance of the apiary.

There are two smartweeds (*Polygonum pennsylvanicum* L. and *P. Persicaria* L.) which are widely known among the beemen as "heartsease", and heartsease honey is well known in the markets. They are near relatives of buckwheat, and the crop comes at a similar time in late summer. The bulk of heartsease honey is harvested in the Mid-West in a region where little can be expected from buckwheat. The yield is uncertain and comes principally in the wet seasons. But little is harvested in seasons when dry weather prevails in spring and early summer. Good crops are sometimes harvested in dry summers that follow very wet spring and early summer seasons. Wet soils seem essential to heavy yields of nectar. Honey from heartsease is strong in flavor, but not dark in color, like that of buckwheat. On light soils the honey is quite light in color, but on heavy soils it is several shades darker. When there is a good honeyflow there is a strong and rather rank odor in the apiary. One can readily tell when the flow starts by the odor which one notices at once when in the vicinity of a beehive. The plants come up in the grain fields and are very widely distributed, so that the acreage is usually large in every farming community in the Mid-West. Acres of the pink flowers are to be seen in fields where oats or other small grain have been harvested, and moist areas in the corn fields will be covered with them. In this region heartsease ranks next to the clovers in volume of honey produced.

The genus *Aster* is widely distributed in all parts of America, and one of its numerous species is likely to be within reach of bees anywhere. In some areas, however, little honey is harvested from asters. It is in the southeastern States from Kentucky to Georgia that the most honey from this source is gathered. In

the Northeast, aster honey is so generally mixed with that of goldenrod that it is difficult to determine how much should be credited to each. Honey from aster is often gathered so late in autumn that there is little opportunity for the bees to ripen it properly, and for this reason it makes poor winter stores.

FIG. 10. Mountain mint, *Pycnanthemum* sp., in the wild grows on soils of low fertility.

With nearly 80 species of goldenrod (*Solidago* spp.) well distributed in all parts of the country, one must be very general in any brief discussion of them. It is difficult to account for the difference that exists among these species in their attraction for the bees in the various honey-producing areas. Probably nearly every species is the source of some nectar under proper environmental conditions, but there are large regions in which we find no reports of goldenrod honey. Some species do yield more honey than others, but nearly all appear to yield in New England and Ontario, while bees are seldom found on goldenrods in Iowa. The honey is deep golden yellow with heavy body and decided but pleasant flavor. Temperature is apparently important in stimulating the nectar flow. Goldenrod yields but little nectar at 60° F or lower, but on warm fall days when the temperature rises above 70° F the bees become active on the flowers in areas where they yield well. More information is needed to enable us to understand the possibilities of a goldenrod location. It is the main dependance in

some New England neighborhoods, yields much surplus in some Gulf Coast areas and is reported as the source of surplus in a few Texas counties. The only rule that can be laid down is similar to the old adage of the prospector, "Gold is Where You Find It".

There are, of course, many other plants which yield a fall crop of honey in limited areas. Spanish needle (*Bidens*) and thoroughwort (*Eupatorium*), for instance, are important to the beekeeper who happens to live where they are abundant, but the total output of honey from them is not important in the nation-wide crop estimates.

Honey from Trees Other Than Fruit Trees

In addition to the maples, willows and fruit trees already mentioned there are many other trees which yield surplus honey in considerable quantity. Of these the basswood or linden (*Tilia americana* L.) is probably most widely recognized. It was formerly the source of large quantities of market honey, but in recent years the basswood forests have been so generally cut that it has disappeared from many markets. There are still, however, some honey producers in Minnesota, Wisconsin, Michigan and Ontario who harvest basswood honey, but they are few as compared to former years. The harvest usually comes in early July or late June and lasts for ten days to two weeks. At times the flows are very heavy and the crops large, but the tree is erratic in its behavior and may bloom for several years with little nectar for the bees. Apparently it is only the old trees that are most dependable. Although the writer has acres of basswood trees on his Iowa farm, it has been several years since the basswood has contributed much to the honey crop.

The tuliptree (*Liriodendron tulipifera* L.) is a large forest tree common to the vicinity of the national capitol. There it is the principal source of surplus honey, and its early blooming offers a serious problem to the beekeeper. Strong colonies often store as high as 100 pounds from it, but strong colonies are not common that early. If the tree were to bloom a month later, the crop might readily be twice as much because of the larger number of bees available for field work at that time. The tree appears, however, to be one of the most dependable sources of nectar, since it yields nearly every year. The secretion is so profuse at times that the bees are unable to carry it away as fast as it appears. The honey is of rather inferior quality unless mixed with that from other sources.

The sourwood tree (*Oxydendrum arboreum* DC) is common to the mountains of the Southeast from Virginia to North Georgia and westward, blooming for two or three weeks in midsummer when the bees are strong in numbers and able to take full advantage of its offering. The honey is highly regarded in the region where it is produced and is largely consumed at home. Honey-producers in that area boast of the quality and claim that it is the finest apiary product of all America. Those who are familiar with the mild honey produced in the clover region might not always agree, but it offers them no competition, since it rarely appears in the same market. Sourwood is found only on acid soils, and is known only over a limited area.

The persimmon (*Diospyros virginiana* L.) is an abundant source of nectar, but there are only a few places where we find it yielding honey in surplus quantity. In southeastern Kansas the beekeepers find that it adds substantially to their crop, and it is reported as sixth in importance among the honey sources of North Carolina. Wherever the tree is present the bees are likely to be found visiting the blossoms freely during its entire period of flowering. Wild blackberries are common over much of the area where per-

simmon is abundant, and honey is quite generally a mixture of the two.

The cajeput (*Melaleuca Leucadendron* L.) is a tree of comparatively recent introduction from Australia where it is known as "tea-tree". It is now quite widely distributed over portions of Florida and other warm areas. It blooms in early winter and yields a very heavy flow of nectar for about six weeks. Strong colonies will gather as high as a super of honey per week during the time of flowering. The honey is of good quality and may be expected to grow in importance in the frost-free areas.

The most conspicuous feature of the Florida landscape is the palmetto or cabbage palm (*Sabal Palmetto* (Walt.) Lodd.). The bloom opens in July or August and yields an abundant crop of high quality honey. At times the honey is thin and requires considerable care in getting it ripened sufficiently to avoid fermentation. The great drawback to some palmetto locations is the lack of sufficient flora to support the bees through the remainder of the year, and some beemen practice migration to overcome this difficulty. The blossoms are sensitive to weather conditions, and weather that is too dry or too wet may spoil the prospects. For this reason

FIG. 11 (*Upper left*). *Robinia pseudoacacia var. Decaisneana.*
FIG. 12 (*Lower left*). Apple blossoms, *Pyrus Malus.*
FIG. 13 (*Right*). Goldenrod, *Solidago speciosa.* (*Photos courtesy New York Botanical Garden*).

abundant harvests are likely to be gathered only about one year in three.

The black mangrove (*Avicennia nitida* Jacq.) is an evergreen tree confined to the sea coasts of tropical and subtropical America, and is a well known source of honey to Florida beemen who occasionally harvest enormous crops from it. Averages as high as 380 pounds per hive are on record. It is very sensitive to frost, and after the occasional freeze that comes to Florida it yields but little honey for several years. It blooms for several weeks in mid-summer when bees are in the best condition for the harvest.

The mesquite (*Prosopis glandulosa* Torr.) is a well known tree in the deserts of the Southwest. It is a small much-branched tree resembling an aged fruit tree, and a stranger in the region might easily mistake a mesquite forest for an abandoned orchard. It is the most important tree from central Texas westward to California. It is the principal source of surplus honey in southwest Texas and yields large quantities in New Mexico and Arizona. After ample moisture in winter it flowers profusely usually in April and again in July. The plant roots very deeply and is able to reach any moisture in the subsoil. It is said to yield honey more dependably on sandy soils than on heavy soils, and the quality of the honey is good. It is not reliable in its yields, however, and individual trees do not bloom every year. While at times the crops are heavy, there are years of almost complete failure.

Space will not permit reference to more than a few of the other more important trees which yield honey. There are many, some of which are important in limited areas and some of which flower for too short a time to permit a large harvest. The honey locust (*Gleditsia triacanthos* L.), for instance, apparently yields an abundant supply of nectar for a very short time, and bees fairly roar among the blossoms for a few hours, but, after three or four days, no more are to be found there. The black locust (*Robinia pseudoacacia* L.) is similar in this respect. It blooms for a somewhat longer time but still too short for large return. Some surplus honey is harvested from it in unusual seasons. The incense cedar (*Libocedrus decurrens* Torr.) of California is the source of large crops of honeydew from trees which are infested with the cypress scale. This insect exudation is stored as honey, at times as much as 100 or more pounds per hive being gathered. Honeydew of similar nature is sometimes stored from oaks, walnuts, hickories and other trees also.

Honey from Shrubs

There are a few shrubs which yield honey in important surplus quantity. In the Southwest the huajillo (*Acacia Berlandieri* Benth.) and the catsclaw (*A. Greggii* A. Gray, *A. Roemeriana* Scheele and *A. Wrightii* Baker), yield good crops of high quality honey. Uvalde, Texas, has become famous because of the large quantities of such honey shipped from there.

In marshy areas along the Atlantic Coast the pepperbush, *Clethra alnifolia* L., yields a heavy white honey of fine flavor. It is very fragrant when in flower and is often planted for ornament on lawns and in parks. The sea myrtle, *Baccharis halimifolia* L., is of considerable importance along the Gulf Coast, as is the gallberry, *Ilex glabra* A. Gray, which is regarded as the finest source of honey in certain areas in Georgia, Alabama and Mississippi.

Some of the shrubs which yield nectar most generously are planted only for ornamental purposes and are not sufficiently plentiful to be of much help to the beekeeper. Cotoneasters are examples of this kind, and the ornamental barberries attract bees in large numbers and would be valuable if sufficiently abundant. Several of the wild barberries are widely

distributed in the West and do yield some honey.

Sumacs yield honey in some regions and little or none in others. *Rhus glabra* L. is reported as important in New England but has failed to attract the bees at any time over a period of 40 years in the writer's garden.


FIG. 14 (*Left*). Red clover, *Trifolium pratense.*
FIG. 15 (*Right*). Pistillate flowers of sea myrtle, *Baccharis halimifolia.* (*Photos courtesy New York Botanical Garden.*)

Honey from Garden Plants

The beekeeper profits from several kinds of garden plants where they are cultivated over large areas. Melons and cucumbers, for instance, yield nectar in great abundance, and in the Rocky Ford district of Colorado and the Imperial Valley of California, where melons are extensively grown, surplus honey is harvested. Where cucumbers are grown in large fields for pickling, honey is likewise harvested from them. Since bees are essential for the pollination of cucumbers, more is heard about the demand for bees on the part of the cucumber grower than of the interest of the beekeeper in the honey crop.

In the seed-growing areas of California good crops of honey are sometimes harvested from parsnip and from celery. Cabbage and broccoli both yield nectar freely, as do mustard and related plants. The honey from cabbage is of fine quality, but since the plants bloom only the second year, it is nowhere available except where seed is grown commercially.

Chives and other species of onions are very attractive to bees, although their honey has an onion flavor when first harvested. This disappears in time as the honey is fully ripened. Wild onions on the prairies of the Mid-West gave much honey to settlers' bees in the early days of pioneering.

Marjoram and thyme have escaped from the old time herb gardens and established themselves as wild plants in many eastern neighborhoods. Both are the source of honey of good quality. Wild thyme covers hundreds of acres in Delaware County, New York, and in southwestern Vermont where it provides excellent bee pasture during August. The bloom usually opens at about the time basswood is finished flowering, and continues until frost, sometimes as late as November. It is a never-failing source of honey, and local beemen report no year without a crop in more than 25 years.

The globe thistle, *Echinops sphaerocephalus* L., is known among the beemen as Chapman honey plant, for it first became known to them through the efforts of Hiram Chapman of Versailles, New York, about 1887. It is of little importance, since it is grown in this country only for ornament. In the Balkans, however, it is said to be cultivated as a forage crop and used for silage. We are told that cows fed on echinops show a decided increase in milk flow. Bees visit the flowers very eagerly as long as they are in bloom. The sugar content of the nectar is high, and it seems probable that with a large acreage it might assume great importance as a source of honey.

The fiddleneck phacelia, *Phacelia tanacetifolia* Benth., a native of California, was taken to Europe where it became very popular as a bee plant and also to some extent as a source of forage. A research project has been reported from Germany for the study of this plant as a means of increasing the yield of forage on farms. There are many species of phacelia and all appear to secrete nectar freely. Several are reported as the source of honey in widely separated areas in Indiana, Texas and California.

Honey from Wild Herbaceous Plants

Following forest fires the beekeeper is likely to find a year or two of fine harvest from fireweed, *Epilobium angustifolium* L. It does not last long, however, for other vegetation soon crowds it out, but temporarily it arouses great enthusiasm and provides beautiful extensive areas of pink flowers which cover the landscape as far as the eye can see. The flowering time is long, usually from July until frost, and occasionally the yield is extremely heavy. It is by no means dependable, however, for the crop may be light, heavy or near failure, depending upon weather conditions. It is seldom heard of as important except after fires which burn over large areas.

The common milkweed, *Asclepias*, is the source of good honey in limited areas, and is best known from northern Michigan where it is found in large acreage. From 50 to 100 pounds of honey per colony is often reported.

In the American Bee Journal Test Garden the anise-hyssop, *Agastache Foeniculum* Kuntze, attracts bees more consistently in all kinds of weather and over a longer period than any other of the hundreds of plants under observation. It has nearly disappeared in the wild, but was once the source of good crops of mild spicy honey in the Missouri River Valley. It is still found in the bush country of western Canada where the beekeepers

report ample surplus from it. The Indians found the plant very useful and used the foliage to flavor other food as well as for making a beverage. In our garden it flowers from June until October and never fails to attract the bees. Early in the morning or late at night, in hot weather or cold weather, wet

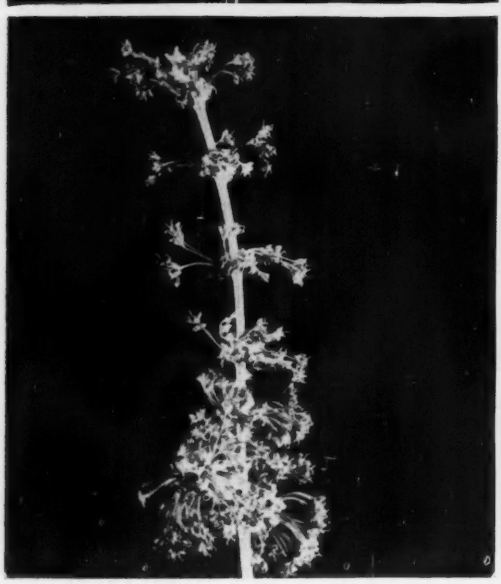

FIG. 16 (*Upper left*). Staminate flowers of big-leaved, or Oregon, maple, *Acer macrophyllum.*

FIG. 17 (*Upper right*). Pistillate flowers of big-leaved maple, *Acer macrophyllum.*

FIG. 18 (*Lower left*). Pistillate flowers of red maple, *Acer rubrum.*

FIG. 19 (*Lower right*). Staminate flowers of red maple, *Acer rubrum.* (*Photos courtesy New York Botanical Garden.*)

Fig. 20 (*Upper*). The Wagner pea, *Lathyrus sylvestris,* is deep rooting, drought resistant, long lived and suited to poor soils.

Fig. 21 (*Lower*). The globe thistle, *Echinops sphaerocephalus, known to bee keepers as* "Chapman Honey Plant", is grown in the United States only for ornament but is said to be used for silage in the Balkans.

weather or dry weather, bees will be found busily seeking its abundant nectar. The sugar content of the nectar is high, and investigation is under way to determine whether the plant can be put to any commercial use which could justify its cultivation.

There are several species of mountain mint, *Pycnanthemum*, which yield honey in midsummer. One has recently attracted wide attention in our test garden as a possible source of essential oil. Prof. Arthur Schwarting of the Nebraska College of Pharmacy has distilled the plants from a measured area and found that *P. pilosum* Nutt. yields an abundant supply of essential oil which contains menthol and thymol in quantities which offer promise of profit for cultivation. Since the plant in the wild grows on soils of low fertility and is usually found on exposed hill tops, it may offer a worthwhile crop for marginal lands where staple crops cannot be profitably grown.

Cleomes are famous for their attraction for bees. One, the purple flowered cleome, is commonly called "Rocky Mountain bee plant" and is the source of surplus honey in some Colorado localities. The yellow spider flower, *Cleome lutea* Hook., is relatively new to gardens where it is arousing much interest. It is found from western Nebraska southwest to California. In its native desert it is not large, but when brought into cultivation on good soil with ample moisture it reaches a height of six or seven feet and by the end of the season may have as many as 300 bright yellow flower clusters. The flea beetles are very destructive to the young plants and make it difficult to maintain them. Otherwise it is of easy culture and would reseed itself readily year after year.

Some New Introductions

Among the promising bee plants of recent introduction may be mentioned the Wagner pea (*Lathyrus sylvestris Wagneri*). A German teacher of agriculture, named Wagner, spent many years in the selection and breeding of this pea from forms in the mountains of Europe, in the hope of producing a new forage crop which would at the same time be a good honey plant. It was introduced to the public more than a half century ago but long lost to sight. It is deep rooting, drought-resistant and long lived, and suited to poor and rocky soils where few plants will thrive. It yields an amazing amount of forage and also appears to supply good bee pasture. It is not suited, however, to ordinary farm rotation, since it requires about three years for establishment. On soils where it can remain for a long time it offers much promise, and for the North it appears to serve about the same purpose as that of kudzu, in the South.

Two new salvias offer much promise for bee pasture. They are the summer sage (*Salvia superba* Hort.) and the meadow sage (*S. pratensis* L.). The former is thought to be a hybrid of recent appearance. Some writers state that it will not produce viable seed, but with us it seeds very freely and grows very readily. The meadow sage comes into bloom about the first of May and lasts until June, thus covering a period when there is little forage for the bees in many localities. The summer sage follows and blooms until midsummer and flowers for a second time in September. Both are attractive in the ornamental garden, but it is thought that by naturalizing them on waste lands, such as strip mine areas, roadsides and other unused areas, they may add much to the available bee pasture.

Birdsfoot (*Lotus corniculatus*) is a relatively new legume which is fast growing in popularity. It is proving adaptable to soils on which the clovers and alfalfa do poorly, being drought-resistant

and longer lived than the clovers in common use. It appears to be entirely dependent on insect activity for pollination and yields honey freely.

Trifolium ambiguum Bieb. is a new clover from Russia which has aroused widespread interest in the American Bee Journal Test Garden at Atlantic, Iowa. It is a long-lived perennial which spreads rapidly from deep underground roots, and is reported as hardy far to the north, even in the alpine zone, and may succeed where common clovers fail. Little is known regarding its adaptability, but it is being tested in hundreds of localities and is under investigation at several agricultural experiment stations. Root cuttings planted about two feet apart in the row and in rows four feet apart have been known to fill all the intervening space and to make a solid planting in little more than one year. The plant blooms freely and secretes nectar abundantly. Bees are able to reach the nectar without difficulty, and if the plant proves adaptable to general conditions, it promises to become important as a source of honey.

Correction Re Citrus Products

GLENN H. JOSEPH

In my article, "*Citrus Products—A Quarter Century of Amazing Progress*" in ECONOMIC BOTANY 1: 415–426, 1947, the sentence in the second column, line 24, page 420, beginning "The albedo contains about one-half of its weight in pectin, on the dry basis, . . ." should have been written as follows: "The albedo contains about one-third of its weight in pectin, on the dry basis, . . ."

When the original sentence was written we had in mind the acid-alcohol-washed albedo, as described on page 424. In that particular product the pectin content is about 50% of the dry weight. However, when one considers the un-leached albedo, on a dry basis, the naturally occurring sugars would be present to dilute the pectin content to about 25–35% of the total dry weight.

This error was called to our attention by Dr. Walton B. Sinclair of the University of California Citrus Experiment Station at Riverside, California. Extensive data on the subject, obtained by Dr. Sinclair, agree with data from our own laboratories to show that the "one-third" value mentioned above is a suitable one to substitute for the "one-half" which was written in error. We are thankful this error was called to our attention and appreciate the privilege of having the correction appear in ECONOMIC BOTANY.

Correction Re Tagua

Dr. Acosta-Solis reports in respect to his article on "Tagua or Vegetable Ivory" in ECONOMIC BOTANY 2: 46–57, 1948, that the percentage figures on pages 52 and 53 should be 28.87, 35.46, 39.75 and 47, respectively.

Rubber–*The Primary Sources For American Production*

Despite extensive war-time investigations of other rubber-containing latex plants, the Pará rubber tree of Brazil remains, by any measure, the world's foremost source, and only guayule and the Russian dandelion display any possibility of becoming secondary sources of commercial importance.

W. GORDON WHALEY[1]

Nature of Latex

THE production of latex, of which rubber is often a constituent, is a characteristic of thousands of species of plants, members of a great number of widely separated families. Latex-bearing plants inhabit such diverse places as the high Tien Shan Mountains of Asia and the rain forests of tropical America. They range in form from tiny scorzoneras to towering heveas of the American jungles, in habit from short-lived annuals to century-living trees.

Despite much research, the function of latex in plants is still obscure. To it have been assigned, at one time or another, rôles in protection, nutrition, transport of substances, and as a fluid reservoir. Though the question is still unanswered, the complex and variable composition of latex suggests that it may actually have more than a single function. Latex is usually constituted of acids and salts dissolved in water containing, in addition, in solution or suspension, any of several other substances. While hevea latex contains no starch, the latices of several species of *Euphorbia* have an abundance of fairly large starch grains (4). The latices of most composites include large amounts of sugar, while those of other species do not. Proteins are sometimes present in great abundance, often together with proteolytic enzymes such as the papain of *Carica Papaya* L. The latex of *Ficus callosa* Willd. has been found (27) to contain more than 90% protein on a dry weight basis. Alkaloids are another common constituent of latex in certain species but are entirely lacking in others. Notable among the alkaloid-containing species is *Papaver somniferum* L. from which the various opium alkaloids are derived. Rubber, with which we are concerned in this article, is found in a great number of latices but is completely absent from many others.

Latex is produced in cells or latex vessels which are living cells containing nuclei and other normal cell constituents. It has been demonstrated (23) that in plants with small laticiferous cells, the latex particles are formed in the cytoplasm and then combined in vacuoles. The same may hold for latex formation in vessels. The region of formation of latex is still not altogether clear. It was early supposed that latex formation takes place in the leaves and that the substance is then carried to the vessels of the rest of the plant. That this cannot be so, at least in all plants, is clear from the fact that some plants, *e.g.*, guayule (*Parthenium argentatum* Gray), have little if any

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rubber in their leaves. Furthermore, some investigators (*e.g.*, 9) have shown that leafless plants form latex readily. It is clear, however, that there is some movement of latex within the vessels and perhaps in the case of some latex components from vessel to vessel. The physiology of latex and its formation has been well discussed by Moyers (19) and will not be considered further.

History of Rubber

Plants which produce rubber-bearing latex are numerous and widespread, but only a few contain rubber of satisfactory quality and in sufficient amounts to be of any economic importance. Of these, the major ones are native to the Americas. In fact, the history of rubber is, except for the story of the tremendous development of the Eastern plantations, essentially an American history.

The discovery of rubber and of the fact that it could be used for a few simple purposes is lost in antiquity. We know only that the early explorers of the western tropics and adjacent regions came upon natives who had developed certain uses for the sticky substance which they obtained from local plants. The first appearance of rubber in the white man's chronicles is a notation by a chaplain in the court of Ferdinand and Isabella that the Aztecs "had a game which they played with balls made from the juice of a certain herb." This reference was written in the year 1510 (30). In 1536 Oviedo y Valdés wrote a long history of the Indians which was not finally published in full until 1851–1855. This history contains a list of a number of different products which were made of latex by the Indians of the Amazon region.

Little by little the white conquerors of the western Indians expanded the uses which the natives had made of latex. F. Juan de Torquemada related in his "De la Monarquía Indiana" (1615) that for several years before 1600 the Indians and Spanish settlers were wearing shoes, clothing and hats made by dipping cloth into latex. However, rubber products made by the primitive methods which the Indians developed had distinct limitations. They responded to warm weather by becoming sticky and to cold weather by hardening and cracking. It was not until many years later that the secret of how to treat rubber so as to improve its qualities and make it a commercially valuable product was learned. The answer came in 1836 when Charles Goodyear invented the vulcanizing process and thus opened the way for the tremendous development of rubber as an industrial product.

The accumulation of knowledge of rubber-bearing plants was begun, so far as the record is concerned, by Charles Marie de La Condamine who was sent to South America in 1734 by the Paris Academy of Sciences, under sponsorship of Louis XV to make a meridian measurement on the equator, in an attempt to settle a question about which there was raging a considerable argument: whether the earth is an elongated or a flattened sphere. La Condamine landed on the west coast just north of Guayaquil, Ecuador, and proceeded over the Andes by way of Esmeraldas. Along the route he came across several examples of the utilization of rubber, principal among which was manufacture of crude torches and candles. The latex being used for this purpose was collected from trees in the Pacific Coast forests and on the eastern slopes of the Andes. La Condamine noted that the name commonly used for the latex-bearing trees of Esmeraldas was "heve".

Cook (6, 7) has pointed out that a good deal of the confusion surrounding the names of the two principal American rubber trees can be traced back to La Condamine's journey over the Andes and down the Amazon Valley. The trees

FIG. 1. A mature hevea tree tapped with a full spiral cut. Costa Rica.

which La Condamine saw on the Pacific coast of Ecuador and on the eastern Andean slopes were obviously of some species of *Castilla*, since this is the only important rubber-bearing genus native to that region.

During his descent of the lower Amazon, La Condamine apparently saw no latex-collecting. In Pará he found a few primitive articles molded from latex. His interest in the product stimulated, La Condamine, when he arrived in French Guiana, initiated a search for latex-bearing trees. François Fresneau, a French engineer who had spent several years in the French Guiana colony, found several trees for La Condamine and prepared brief descriptions and drawings of them. La Condamine made two reports on rubber in addition to sending a sample of the stuff to the Paris Academy in 1736. In 1745, in his general report on his trip (published in 1749), he described it and the uses which were made of it by the Omagua Indians, giving the name as "cauchuc" (French, caoutchouc). In a 1751 paper (published in 1755) devoted exclusively to his observations on latex, its source and uses, La Condamine cites "heve" or "jeve" as the name adopted by the Spaniards from the Indians who so designated the latex-bearing tree. In the same paper he published Fresneau's description and figure. La Condamine, who was a mathematician and astronomer and not a botanist, made no attempt to distinguish between the Pacific Coast or East Andean trees and those of French Guiana. To him they were both simply latex-bearing trees.

In 1775 Fusée Aublet described, in a four-volume work on the plants of French Guiana, one of the native Guiana latex-bearing trees and gave it the name of *Hevea guianensis*. Aublet derived the genus name from "heve" which he attributed, as had La Condamine from whose work he may have gotten the name, to the inhabitants of Esmeraldas in Ecua-

dor. He, too, was apparently unaware that he was dealing with a different tree. Thus one of the native names for the castilla tree became the genus name for a totally different latex-bearing tree growing in a different part of South America, solely because both trees had in common the production of latex.

To La Condamine should go credit for being the first man to envision the possibility for widespread use of rubber. However, not much attention was given to the material until almost a century later. The chemist Priestley generally is given credit for having discovered a very simple use for the substance when he noted that it would erase pencil marks when rubbed over them. It has been pointed out (28), however, that it was actually a chemist named Edward Nairne (1726–1806) who made this observation. Because of this property Priestley named the substance "rubber" and, because the samples had come from India, "India rubber", a name which still clings.

FIG. 2. Fruit of *Hevea brasiliensis.*

A major advance in the development of uses for the material was Charles Mackintosh's discovery, made in 1833, that rubber can be dissolved in naphtha. This finding opened the way for the

development of various manufacturing procedures. Earlier it had been necessary to manufacture rubber goods directly from fresh latex, and hence the manufacturing process could be carried out only in the immediate vicinity of the latex-bearing trees.

FIG. 3. Balls of rubber being cut for inspection at Manaos, Brazil.

The real rise of rubber began with Charles Goodyear's invention of the vulcanizing process. Goodyear found in 1839 that when rubber and sulphur are mixed in the presence of heat, a chemical alteration is brought about which greatly changes the character of the mixture. Rubber so vulcanized gains in strength and becomes resistant to weather changes. Goodyear's vulcanizing process is the cornerstone of the rubber-manufacturing industry, and its discovery gave rise to an immediate development of numerous uses for the substance, and thus to a marked increase in demand. The later development of the automobile industry and the invention of rubber tires gave the impetus which has made rubber collecting and production one of the world's most important industries.

In the first great rubber boom, collec-

tion was solely from wild plants, most of them in the American tropics. Of the hundreds of species of latex-bearing plants which were sampled during this time, only a few assumed significance in the commercial collection of rubber. Of these the principal ones are species of *Hevea* and species of *Castilla*. *Manihot Glaziovii* Müll.-Arg. and a species of *Sapium* were at one time of some importance in rubber production, but their latex is now collected only in very small amounts. Of all the plants, the most important in the long run has proved to be hevea.

Hevea planting material was transferred from Brazil to England in 1876 and then from England to the eastern tropics where several decades later planting of *Hevea* in commercial plantations was undertaken on a tremendous scale. It is from these Eastern plantations that the world's great supply of natural rubber has been mainly derived since about 1914.

The tropical American latex-bearing plants supplied almost all the world's rubber from the period when the product began to assume industrial importance until the development of the great Eastern plantations. From this time until the recent war years, rubber collection from wild sources in tropical America was a declining industry, though it furnished a few thousand tons each year. During the war, the cutting off of the Eastern plantations gave great impetus to the collection of wild rubber in the western hemisphere as well as to attempts, several of which had been begun much earlier, to establish rubber plantations within certain of the Latin American countries, and to attempts to grow such rubber-bearing plants as can be cultivated within the borders of the United States. In the light of these attempts, *Hevea* still is, by any measure, the most important genus of latex-bearing plants.

Nomenclature and Taxonomy of *Hevea*

As a result of the original confusion there has been some argument over the proper name for the genus. After Aublet's description of *Hevea guianensis* as the type species there were several attempts to get away from the name *Hevea* and its association with another tree. In the 1789 edition of Linne's "Genera Plantarum", the second volume of which appeared in 1791, the genus is listed as follows:

1466. SIPHONIA + Hevea Aubl. 335

In 1858 Baillon published a study of the Euphorbiaceae, in which he listed the genus in the following manner:

SIPHONIA Rich.
Cahuchum Rich.
Hevea Aubl.
Jatropha L. fil.
Micrandra R. Br. (non Benth.)
Siphonanthus Schreb.

In 1865 Mueller von Aargau returned to the use of *Hevea* as the genus name, and this name has been retained throughout all of the more recent publications, though Cook attempts to straighten out the matter of terminology and advocates a return to the name *Siphonia* which he believes has proper precedence, since the use of *Hevea* as a homonym was once discarded.

The number of species in the genus *Hevea* is also somewhat confused. In Martius' "Flora Brasiliensis" the Euphorbiaceae were treated by Mueller von Aargau in 1873–74. In this "Flora" 11 species were recognized. In Engler's "Das Pflanzenreich" Pax (1910) recognized 16 species. More recently Huber (1906, 1913) has listed 24 species, but Ducke (1935) has stated that the number is certainly fewer than 20 and that he has found only 12 good ones. Later studies would seem to indicate that the

number of species is less than was earlier supposed. The difficulties in distinguishing species lie partly in the fact that many of the characteristics are not distinct, nor the differences of great magnitude, and partly in the fact that several species and subspecies apparently hybridize freely.

Distribution of Hevea

The distribution of the various species of *Hevea* has not been well worked out, primarily because travel and exploration in the Amazon Basin are difficult. Members of the genus are confined to rain forest areas and are distributed throughout the whole Amazon region—in Brazil, Colombia, Peru and Bolivia. Ule (26) published a map of the distribution of various species in which he reported 11 species as characteristic of the area north of the equator and seven species as characteristic of the area south of the equator, but Huber and others have pointed out that such a sharp segregation does not actually exist. Of the species which are spread throughout Amazonia, only four are tapped for their latex: *H. brasiliensis* (HBK) Müll.-Arg., *Benthamiana*, (HBK) Müll.-Arg., *lutea* (HBK) Müll.-Arg. and *guianensis* Aubl. Of these only *brasiliensis* and *Benthamiana* are of any considerable importance and only *brasiliensis* is really outstanding. It was *H. brasiliensis* which was transported from Brazil to the Orient by way of England, and which has come to be the most important source of natural rubber. *H. brasiliensis* is limited to lowland rain forests or to upland forests with a very high rainfall. Its normal range covers the whole lower Amazon Valley and extends along the banks of the rivers for a considerable distance into the uplands. Trees of this species ordinarily vary from 12 to 50 meters in height, those in the lower Amazon generally being around 15 meters and those in better soil along the upper rivers being much taller.

Hevea Latex and Tapping

The latex in *Hevea* is contained in latex vessels in the cortex. The vessel system consists of a number of networks of vessels making up a series of concentric open cylinders. The vessels in each cylinder are variously interconnected, but the existence of connections between cylinders has not been established. The whole system is more or less irregular as to its branching, and there are frequent alterations in the size of individual vessel segments. Latex is collected by tapping methods which are similar to those that have been used for many decades. A worker who intends to tap *Hevea* trees selects an area in which there are a number of trees and clears a trail from one tree to another, usually describing a rough circle, and returning finally to the starting point. A cleared "estrada" will contain from 40 to 325 trees, depending in part upon the distance between trees and in part upon the ambitions of the tapper. Usually two or three or even more "estradas" are cleared around a central point, and each is tapped in turn on successive days. Tapping is begun early in the morning, and the tapper progresses from tree to tree until he has completed the circuit.

There are various methods of tapping *Hevea* trees but all involve making a wound in the bark in such a way that latex running from the wound will flow into a collecting cup which is attached to the tree. The physiological reactions involved in tapping responses are complex. They have been reviewed by Frey-Wyssling (10). The first latex yielded contains a high percentage of "solids". In fact, immediately after the first tapping the latex may be so concentrated that it will hardly flow at all. As flow continues the latex becomes more dilute. When a tree is retapped after an interval the "solid" content of the latex is found to have been restored. Only a few hours are necessary for this "rejuvenation".

The rate of flow of latex decreases with time until finally it stops and coagulation takes place over the wound. Frey-Wyssling has calculated that latex moves to a tapping cut from a distance of approximately one meter. In careful plantation tapping, after the original incision has been made, a thin shaving of bark is sliced off at each successive tapping. The first cut is made at a distance of about a meter above the ground, and the tapping panel is cut downward until it nearly reaches the ground level. The principal systems are either a one-third spiral, a half-spiral or a full spiral tapping. The incisions are made with the utmost care so as to open the full thickness of bark, but not to injure the cambium and thus prevent healing of the tapping panel. In the collection of jungle rubber, tappers are much more likely simply to make several incisions at about equal intervals around the tree and to place a collecting cup under each. Once tapping of the whole circuit of trees has been completed, the tapper makes a second round, collecting the few cubic centimeters of latex from each tree and returns finally to his starting point with the container of about two gallons of latex. This latex is then smoked over a fire.

FIG. 4. Seedlings of *Hevea brasiliensis* being sprayed to control South American leaf blight. Turrialba, Costa Rica.

Smoking and Coagulation

The smoking is accomplished by coating latex on a pole which is suspended over a smoking cone of clay or sometimes metal. After one section at the middle of the pole has been coated with latex and smoked, more latex is poured over it and the smoking continued until finally a ball which may weigh between 125 and 200 pounds is built up. Building up of this large ball of rubber usually takes a considerable period of time. Rubber

may also be smoked on square paddles which are dipped into the latex and then smoked and then redipped and smoked again. With this method one day's collection of latex is usually smoked and then removed from the paddles.

Smoking not only coagulates the latex but it also conditions the rubber. La Rue (16) points out that fruits of *Attalea excelsa* Mart. were long used to smoke the finest grades of Pará rubber, and that because of this use their export was prohibited by the Brazilian government. While many woods and other plant parts are used for smoking the rubber, some are definitely better than others.

In plantation practice trees are planted in various patterns, usually from 12 to 24 feet apart, with 20 feet or more between rows. Plantations are kept free from wild growth either by intercropping with food or other plant crops between the rows, or by the use of cover crops. The collection of latex from such closely spaced trees is, of course, much simpler than its collection in the jungle. The handling of trees of approximately the same age and size permits much more careful tapping and much greater care in the collection of latex. On plantations, small amounts of ammonia or other anticoagulant may be added to the latex as it is collected to preserve it without coagulation until it can be shipped to the nearest mill. At the mill latex may be prepared for shipment as latex by concentrating it or may be prepared for shipment as sheet or bulk rubber. In the latter case, the latex is poured into large tins, and some coagulating agent is added. Coagulation takes place in a few hours, and the blocks of soft coagulated rubber are then taken from the coagulating pans, washed and run between rollers which reduce them to thin sheets. These sheets are then smoked by hanging them in the smokehouse in which fires have been built or into which smoke is forced. After smoking, the rubber sheets, which have become amber to brown in color, elastic, dry and not sticky, are pressed into bales for shipment.

Production

Production of rubber on the plantations of the East began about 1900, and in 1912, when the Amazonian peak production was reached, the Eastern production began to assume considerable importance. In that year plantations there produced 28,516 tons. From that time on Eastern production continued to increase, and the economics of operation under the plantation system gave Eastern rubber a price advantage which had a very discouraging effect upon the collection of wild rubber in the western hemisphere. Operations in the Amazon began a decline which, except for a brief period of stimulation by the first World War, continued steadily until the 1920's.

American Production and Problems

Concentration of some 97% of the world's rubber production within a limited area in the Orient has always had serious implications for the United States which is the rubber producer's main market. There has been an ever-present danger of the cutting off of supplies from such distant parts. Furthermore, most of the production was for many years under very tight economic control by British and Dutch colonial interests. By the use of restriction schemes of various sorts, the price of rubber, and hence its use, has been purposely affected several times by the British and Dutch to the detriment of the United States consumer. For these and other reasons there have been numerous attempts to establish large-scale rubber-producing operations outside the Orient. The first of these major attempts was made by Harvey Firestone who started plantings in Liberia with the idea of supplying his own rubber needs. In 1928 Henry Ford began the establishment of rubber planta-

tions on part of a two and one-half million acre concession on the Rio Tapajos in Brazil. In 1935 the Goodyear Tire and Rubber Company began a similar venture in Panama and in the following year extended it into Costa Rica. All of these western hemisphere plantings, together with numerous other plantings begun earlier in the 1900's in British Guiana, Dutch Guiana and Trinidad, failed in spectacular fashion after seeming through their initial stages to be destined to succeed. They all failed principally because of infection of the trees by South American leaf blight. This disease is caused by the ascomycete *Dothidella ulei* P. Henn. Leaf blight has been present for many years over the native range of *Hevea brasiliensis* in the Amazon, Orinoco and Paraná basins. When *Hevea* plantings were made, it appeared in the Guianas and in Trinidad, Panama, Costa Rica, Colombia and more recently north as far as Mexico. The fungus appears to be limited to species of *Hevea* as hosts, and *H. brasiliensis* is particularly susceptible. It is spread mainly by conidia, although ascospore infection may also be important. The fungus generally infects the unfolding young leaves, but it may attack any young tissue. The severity of the disease depends particularly upon the amount of moisture present, the amount of inoculum, temperature and the density of plantings. Under natural conditions serious damage to hevea by *Dothidella ulei* is unusual. This apparently results from the fact that hevea trees commonly occur sparsely over wide areas, and that between individual trees there are dense barriers of non-susceptible species. However, when plantings are made in stands dense enough to be economically practicable, and the disease appears, it spreads rapidly and will completely defoliate acres of plantings in a single season. It has been understood for many years that any successful establishment of hevea plantations in the western hemisphere depends on the development of successful methods for the control of South American leaf blight. Largely as a result of the wartime program of rubber plant research, a satisfactory degree of control of South American leaf blight was finally obtained. The first step in this control was the development by plant pathologists of the United States Department of Agriculture and the Goodyear Rubber Plantations Company of new methods and adaptations of older methods for the control of leaf blight by spraying. These methods use copper and sulphur fungicides with the addition of various spreaders and stickers, among them casein, wheat flour, potassium fish-oil soap, a rosin-residue emulsion and various vegetable and mineral oils. The problem of spraying effectively is par-

FIG. 5. Indian method of slashing Castilla trees. Guatemala.

ticularly difficult with hevea because the leaves have a thick waxy cuticle and because plantings are practical only in areas of very high rainfall. However, the methods which have been developed are very effective, particularly for seedlings grown in dense nursery plantings. The attack upon South American leaf blight has been discussed in detail by Langford (15).

In plantings of mature trees spray control of this sort would be both mechanically almost impossible and economically prohibitive. Ultimate solution of this disease problem lies in development through selection and breeding, or by other means, of trees which are either immune or at least highly resistant to attacks by the fungus. As long ago as the plantings were made in the Guianas it was seen that different strains of ***Hevea brasiliensis*** vary considerably in their susceptibility to attacks by the disease. From the early Ford and Goodyear plantings there were isolated a number of trees which appeared to be highly resistant. A second attempt at establishing Ford plantings was made using these resistant strains. However, they were not satisfactory for use in commercial plantings because they all turned out to be very low-yielding trees. But the existence of such resistant strains points to the possibility of selecting resistant lines among the higher-yielding types. Such resistant strains also furnish planting stock for the combination of resistance and high yield, and supply grafting stock, by which combination high-yielding and resistant trees can be propagated. Work of the United States Department of Agriculture rubber research people and associated investigators has been directed, over recent years, toward attempts to solve the disease problem by using three methods. Yield and resistance tests have been made on thousands of trees. They were made first on the segregates from the early western hemisphere disease-resistant plants. Many turned out to have a considerable degree of resistance, but all proved to be low-yielding. The same kind of tests were made on Eastern clones brought back to the western hemisphere by way of the Philippines. Many of these were very high-yielding, but all of them were extremely susceptible to disease. Within the last three years tests have been made on a large number of new strains, the planting material for which has been brought principally from the jungles of Brazil and Colombia and established in experimental fields in Costa Rica, Peru, Haiti and Mexico. Advantage was taken of the increased tapping of wild trees during the war, and where the yields of such trees appeared to be high, budwood was cut from them. Some of the trees collected in this selection program give promise of having high yield combined with a satisfactory degree of disease resistance.

The second method for the production of high-yielding, resistant strains is by crossing known resistant lines with known high-yielding lines and then selecting progeny from them on the basis of evaluation of yield and resistance. This approach bids fair to produce trees which would be satisfactory under any western hemisphere conditions, but the procedure is such as to necessitate long-term operations.

The third method which has been resorted to in an attempt to hasten production is the combination of resistance and high-yield in a single tree by use of a double-budding procedure. The method had its origin in the work of Cramer in Java. Cramer was interested in the possibility of increasing yields and controlling certain local diseases. To this end he suggested double budding to combine three strains, root, trunk and top, each selected for superiority under a given set of conditions. The technique involves a number of factors of compatibility,

growth relations and developmental patterns, but several combinations have been developed, making use of native root stocks, high-yielding Eastern clonal trunks and disease-resistant tops. In practice, a high-yielding strain is budded onto a wild root stock as soon as the plant is large enough. These budded trees are grown in the nursery under spray control until they are six or seven feet high. They are then top-budded, using a disease-resistant strain or another species of disease-resistant hevea.

Advantage has been taken of these different techniques in the attempt to foster planting of hevea in several of the Latin American countries (5, 24). The United States Department of Agriculture is cooperating with the governments of these countries by furnishing technical assistance and advice on the planting of hevea. To fit the pattern of Latin American agriculture and the economic organization of the various countries, much emphasis is being placed on development of plantings small enough to be managed by a single individual or a single family. Such plantings are possible without disruption of the labor pattern and with relatively little capital. They add an element of diversification to an agricultural pattern which has great need for diversification. Furthermore, rubber can take the place of some lowland coffee which has been much overproduced in countries like Guatemala and of bananas which have been wiped out by disease in several Latin American areas. As a cash crop it is hoped that eventually it will offer support to many currently stranded agricultural populations.

Along with these small plantings larger ones are being undertaken by a few American companies and in one or two cases by Latin American governmental agencies. The aim of the Latin American republics in this planting program is to supply at least a part of their own rubber needs. The interest of the United States is partly to provide the Latin American countries with a noncompetitive agricultural material and partly to insure the presence nearby of at least a small nucleus of plantings from which rubber supplies could be taken in case of future emergency.

Castilla

Second most important of the rubber-bearing trees of the western hemisphere are certain species of the genus *Castilla*, tropical members of the mulberry family. It is probable that most of the early collections of rubber by Central and South American Indians were from castilla, of which there are some ten species extending through Central and northern South America. Until about the middle of the 19th century castilla was far more important than hevea in the collection of rubber which was exported from the Amazon region. Most important of the species in the Amazon Valley is *C. Ulei* Warb. Under favorable conditions trees of this species grow to approximately the same size as hevea. They are found over a somewhat wider range of latitude, and are much more characteristic of the upland territories, generally growing in places which are considerably less wet than those inhabited by hevea. The rubber in *Castilla* is contained in a latex system which differs from that of hevea by not being an anastomosing system. Latex is obtained from *Castilla* in either of two ways; by tapping the trunks with a series of slanting cuts, somewhat like the primitive method used with hevea, or, commonly, by felling the trees and tapping the fallen trunks by cutting rings through the bark at frequent intervals.

When standing trees are tapped, a reasonable amount of latex is obtained, but an interval of some months must elapse before another tapping can be made. It is probable that *Castilla* cannot be tapped more than three or four times a year. Tapping felled trees will yield

from 25 to 70 pounds of rubber per tree. Much of the tapping has been done by this method. The majority of the tappers in the Amazon Valley seem to prefer felling castilla trees for their rather high yield to continued tapping of hevea. As a result, by the late 19th century serious inroads had been made into the native stands of *Castilla.*

When the first thoughts were given to the possibilities of plantation development, it was natural that attention be directed to castilla. The planting of castilla trees was begun in Mexico as early as 1867, more than a quarter of a century before the planting of hevea in commercial plantations in the East. When in 1899 President McKinley suggested planting of rubber in the Philippines, Hawaii and Puerto Rico to bring at least some part of the United States' supply within territory over which the American people had control, he stimulated extensive investment in and development of castilla plantings in Mexico and Central America. Though there was a series of fraudulent enterprises in the great rubber boom that resulted, there actually were some 30 million trees planted. Except for very minor contributions to the world's rubber supply, some of them during the critical war years 1941–1945, all these plantations came to naught, for the competition of hevea was too great. In terms of annual yields castilla gives one to two pounds of rubber as against 10 to 25 from hevea.

FIG. 6. Guayule in cultures to study its mineral nutrition requirements. Plant Industry Station, Beltsville, Maryland.

Though castilla rubber is generally

considered to be inferior to that of hevea, it is an acceptable high-grade rubber. Much of its reputation for poor quality has come from its comparison with more carefully collected and prepared hevea rubber. In the common practice of felling castilla trees, the latex is collected by simply digging holes in the ground under the felled tree and allowing the latex to flow into these holes to coagulate. This, of course, makes for a great deal of contamination with soil, twigs, leaves and other materials. Castilla has fallen behind hevea mainly because of its low yields and the difficulties of developing satisfactory methods of tapping.

Guayule

The most important rubber-bearing plant native to the United States is guayule (*Parthenium argentatum* Gray). Guayule was "discovered" in 1852 by Dr. J. M. Bigelow who was a member of the Mexican Boundary Survey party. The plant was first described botanically and named by Asa Gray in 1859. *Parthenium argentatum* is a low-growing, profusely-branching shrub of the family Compositae. Under natural conditions it seldom reaches a height of more than two feet. The young stems and the small leaves are of a silver-gray color, the leaf form usually being somewhat variable. Flowers are borne in close heads, are small, and the ray florets are white. The plant is native to the north-central plateau region of Mexico and the Big Bend area of Texas. Within its native habitat it is usually restricted to limestone soils in regions having a rainfall of 10 to 15 inches a year. Actually the plant will grow somewhat better under conditions of higher rainfall, but in the higher rainfall regions it will not often survive competition from other plants. In habit the plant is a hardy perennial, living under normal conditions for as long as 30 to 40 years. The rubber in guayule is found distributed throughout all the plant organs, but in considerable quantity only in the stem and root. The rubber occurs in latex in individual cells rather than in latex vessels or tubes. According to Artschwager (1), in plants of harvest size the greatest concentrations of rubber are found in the vascular rays of the phloem and of the xylem, with the xylem containing lesser amounts. Rubber is located also in the cells surrounding the resin canals, and in smaller quantities in the pith, primary cortex and xylem parenchyma. Artschwager reports that in young actively growing stems rubber appears first in the cells surrounding primary cortical and pith canals, and in the secreting layer of the incipient secondary resin canals. In older root and stem structures rubber secretion is, according to Artschwager, related to the age of the cells. Rubber appears first in the older cells; thus cells close to the cambium or nearer to the apical meristems contain less rubber.

The rate of rubber formation in relation to growth in guayule has been a subject of very considerable investigation. It is generally recognized that rubber formation takes place more rapidly during periods in which conditions are not favorable for extensive vegetative growth. However, the amount of rubber formed is dependent on the degree of vegetative growth and of protoplasmic synthesis which have preceded the onset of conditions favorable to rubber formation but not to growth. The rubber content of guayule increases over a period of at least several years. The amount formed differs with the age of the plants, from location to location and from one strain to another as well as from season to season. Seven percent rubber on a dry-weight basis has been generally accepted as the average of wild shrubs. Cultivated crops of selected types will contain as much as 22% after four or

five years growth and even more if grown under special conditions.

The potential value of guayule rubber was first recognized by the Germans just before the turn of the century. Then, in 1904, a factory designed to extract rubber from guayule was set up in Torreon, Coahuila, Mexico, and commercial extraction and processing of guayule rubber was begun. Several other factories were later constructed. Except for one short period when the price of rubber was very low, guayule rubber has been on the market since the opening of the first processing plant. For most of this period the shrub has been collected and processed only in Mexico, though for some time there was production in Texas. It was recognized many years ago that the supply of wild guayule is strictly limited and that any considerable exploitation would utilize all the available shrub within a very few years. Conservation measures were accordingly taken in Mexico to prevent such exhaustion.

FIG. 7. Wild guayule. Texas.

Promotion

For many years prior to 1941 the Inter-Continental Rubber Company had been investigating the possibility of cultivating guayule as a crop. With the entrance of the United States into the war the efforts to cultivate guayule as a source of rubber within this country were given great prominence.

Early in 1942 Congress authorized the purchase of the holdings and records of the Inter-Continental Rubber Company at Salinas, California, and the organization of a project aimed toward the establishment of large acreages of guayule, if after some preliminary investigation such establishment seemed to be possible. A program of establishment and supporting research was organized

by the United States Department of Agriculture, with the Forest Service assuming responsibility for certain production work. The Bureau of Plant Industry, Soils and Agricultural Engineering conducted research on the physiology, genetics, anatomy, diseases and general behavior of guayule in relation to attempts at production. The Bureau of Entomology and Plant Quarantine conducted research on the insect enemies of the plant, and the Bureau of Agricul-

FIG. 8. A flowering plant of *Taraxacum kok-saghyz*

tural and Industrial Chemistry studied assay and extraction methods in an attempt to improve procedures for the recovery of rubber. This huge program had numerous ups and downs as the need for natural rubber appeared first very great, then somewhat diminished with advances in the production of synthetic rubbers, and then again became critical when it was realized that synthetic rubbers are not satisfactory for all essential purposes. With these changes in emphasis came changes in plans for guayule rubber production. Finally, only some 35,000 out of an originally projected 100,000 acres of guayule were planted and maintained for any considerable period. During the conduct of the research, the basic behavior of guayule with respect to its vegetative growth and rubber formation under varying conditions was worked out in detail. By selection and breeding, rubber content of the plant was very materially increased, its growth pattern was improved and it was made generally more adaptable to cultivation. The diseases of the plant were catalogued, and control methods were worked out. In general, the plant and knowledge concerning it were brought to the point where serious consideration could be given to it as a real contender for a position of great importance in the emergency production of rubber. On a more limited scale, fundamental research on guayule is now being carried out by several agencies charged with the responsibility for avoiding future shortages of natural rubber.

The rubber which is produced in guayule is a highly resinous product of a grade and quality not altogether satisfactory for general use. Considerable attention has been given to the possibility of de-resinating it so as to extend its general usefulness. Whether such a procedure will prove economically feasible is not yet known. Meanwhile, guayule rubber continues to be in demand for uses in which it is combined with other compounds in which its resins are desirable.

Russian Dandelion

Though not an American plant, one of the most important plants in any consideration of the domestic rubber situation is the so-called Russian dandelion which was introduced into the United States as part of the war-time rubber pro-

duction effort. *Taraxacum kok-saghyz* Rodin was discovered in 1931 in the Tien Shan mountains of Kazakstan by a member of one of several expeditions sponsored by the Government of Russia in an attempt to discover new or better plants which would contribute in Russia's effort to develop domestic supplies of all critical materials originating from plants.

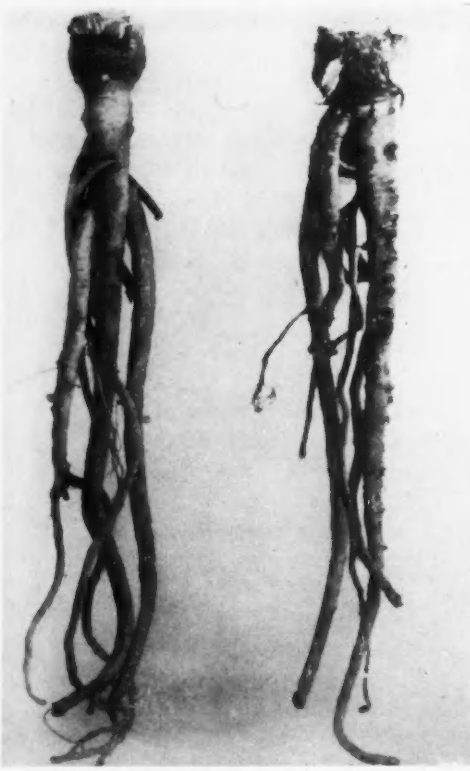

FIG. 9. Roots of Russian dandelion.

The plant is a member of the Compositae, readily recognizable as a dandelion. It consists of from 25 to 50 leaves arranged in a rosette which may either hug the ground closely or be somewhat erect. Its leaves are variable in shape and size, generally somewhat smaller than those of *Taraxacum officinale* Weber. They usually have thickened, prominent midribs, and are characteristically gray-green in color. One of the few constant distinguishing species characteristics is the presence of projecting horn-like appendages at the tips of the bracts which surround the buds. After discovery of the plant, studies were begun in Russia to determine the possibility of growing it there as a crop and to work out the techniques of cultivation and production. By 1935 it was apparent that kok-saghyz held the most promise of any of the plants which had been selected as perhaps representing potential crop plants for the production of rubber. By 1939 plantings extending over considerable acreages in Russia were yielding an average of about 25 pounds of rubber per acre, with some of the plantings producing several times that much. Interested persons in this country had followed the discovery and efforts to develop this plant and had attempted as early as 1934 to obtain some seed for trials. Seed was not obtained, however, until May, 1942, at which time the Russians provided, in response to a request for seed to be used in developing a tremendous production program, some five tons of it. Unfortunately for the attempt at production, this five tons of seed was all unselected material containing seed of many different strains of kok-saghyz, some of them of high rubber-yielding capacity, most of them of low rubber-yielding capacity, as well as seed of several other dandelions. Because of this fact yields from plantings made with this seed were so low, and consequently the cost of producing the rubber so high, as to make the use of kok-saghyz as a source of rubber impractical, even under war-time conditions.

Rubber in kok-saghyz is contained in latex which is produced and stored in latex vessels. If one examines ungerminated seed, no latex vessels are found. Differentiation of the vessels begins as soon as water is absorbed during germination, the first ones appearing in the primary phloem. Secondarily, latex elements are differentiated close to the cam-

bium. The vessels are produced by fusions of tandem cells, the vessels of the same ring being joined to each other at various levels. There are no connections between vessels of different rings. In mature plants latex vessels are distributed throughout the root and leaf tissues. The rubber which is formed in the latex vessels of the root is a distinctly different product from the rubber found in the latex vessels of the leaves. Root rubber has a low percentage of associated resins and is generally considered to be a very high quality product. Leaf rubber has a high percentage of associated resins and is a very poor product. This difference in rubber quality makes it necessary to remove the leaves before harvesting the roots so as to avoid contaminating the root rubbers with the low grade leaf rubbers.

During the war years some 750 acres of experimental kok-saghyz plantings were made at various places in 42 States. It was early apparent that the plant is adapted only to growth in the northern tier of States and in Canada during the summer. The most successful plantings were those in Vermont, Michigan, Wisconsin, Minnesota and Oregon. Whether adaptation of the plant to this area is altogether a matter of temperature or whether light and other factors are concerned is not yet known. Successful winter plantings have been made in Florida and Texas. The experimental planting made possible the development of fairly satisfactory methods of cultivation of kok-saghyz and produced enough rubber for extensive physical and chemical analyses as well as for fabrication and performance tests. The war-time efforts with kok-saghyz have been reviewed by Whaley and Bowen (29). Cultivation of the plant is reasonably simple, though it will be necessary to develop a much more vigorous and competitive plant before economical planting would be possible. The quality of rubber which was obtained from the experimental plantings proved to be equal to or, in a few cases, slightly better than hevea rubber used as the standard.

The most important product of the experimental plantings was, however, something else. It was possible to segregate from the wild stocks sent to this country by the Russians, plants having much greater vigor than the average plants having 25 to 30 times the average root weight, and plants having up to 25% rubber on a dry weight basis, as compared to 3% to 4½% on the average. It would thus seem possible to increase yields of kok-saghyz rubber from 60 to 70 pounds per acre to perhaps 400 to 450 pounds per acre by continuing selection and breeding of the plant. How much additional increase might be expected from the development of better means of cultivation or the finding of more particularly suitable areas is not known at this time.

Along with the kok-saghyz investigations there has been experimental work with *Taraxacum megalorrhizon* (Forsk.) Hand.-Mazz., often called "krim-saghyz," and *Scorzonera tau-saghyz* Lipschitz and Dosse. Both these plants produce considerable rubber and appear to be worthy of further investigation.

Other Rubber-Yielding Plants

There are, of course, hundreds of other plants in both tropical and temperate America which contain rubber. Perhaps most notable among them are the few that were investigated to some extent during the war period. Two species of *Cryptostegia*, *C. grandiflora* R. Brown. and *C. madagascariensis* Bojer., introduced into the western hemisphere from Madagascar, produced a good grade. An attempt was made to develop large scale *Cryptostegia* plantings in Haiti during the war, but the difficulties of extracting the rubber proved to be too great, and the venture was a failure.

These species of *Cryptostegia* are of interest primarily because it has been possible to study the inheritance of certain factors in latex formation in the two species and in hybrids between them.

Several of the native species of *Asclepias* contain fairly large amounts of latex, and some of them contain rubber. However, none of them contains rubber of a high enough quality or in large enough amounts to be of economic interest.

Various species of *Solidago* also contain fairly large amounts of rubber, most of it produced in the leaves. Thomas A. Edison had begun investigations of goldenrod species as potential sources of rubber in the 1920's, and from Edison's work have come some selections with considerably increased rubber yields. But goldenrod rubber is a low polymer rubber and is not considered to have much promise.

Despite all attempts to produce rubber from other plants, *Hevea brasiliensis* remains pre-eminent as the rubber-bearing species, and guayule and the so-called Russian dandelion are the only two other plants produceable in the Americas that have any likelihood of ever becoming important in rubber production.

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Utilization Abstracts

Wood Flour. Wood flour, *i.e.*, finely ground sawdust, shavings and other forms of wood waste, is acquiring increasing importance in a variety of industries, particularly in the manufacture of linoleum and plastics. Users of wood flour formerly depended much upon imports of the material, which reached a maximum in 1929, but during recent years domestic production has been meeting the demand more and more. In 1939, 45,000 tons worth $775,000 were produced in the United States, and present day annual production is about 65,000 tons. The flour is graded according to fineness, color, resin content, *etc.* Fineness ranges from 50 to 140 mesh, most of it being 80, and prices have varied from $25 to $45, and even as high as $75, per ton.

White pine makes an excellent grade, and more than one half of the wood flour produced in the United States is estimated to be from that species. Poplar, spruce, hemlock, maple, birch, fir and other pines furnish the other half.

The uses may be summarized thus:

Linoleum. Accounts for over 40% of domestic use, chiefly as a filler in inlaid types.

Explosives. Mixed with nitroglycerine to make dynamite.

Plastics. Used as a filler in the phenol and urea-formaldehyde types.

Plastic-wood Products. Used in filling cracks and crevices.

Veneer Bonds. Mixed as a filler with phenol and urea-formaldehyde resins for dry glues in veneers.

Composition Flooring. Mixed with caustic magnesia cement to produce resiliency and to permit troweling.

Insulating Brick. Mixed with kaolin and then burned out under high temperature, thus contributing porosity to the brick. (*R. S. Aries, Chemurgic Digest 6(3): 49. 1947*).

Orris Root. Orris root, pulverized and used in medicine and perfumery, is a product of several species of *Iris*. The principal one, *I. pallida*, is extensively cultivated on the hillsides of Tuscany in west central Italy, and production of the root centers about the towns of San Polo, Greve and Figline. In spring the countryside is covered with beds of orris, the flowers white with pale blue veins. Less extensive cultivation is carried on in Alpes Maritimes and Var Provinces of southeastern France.

Near Verona two other species are cultivated, *I. florentina* and *I. germanica*, but their rhizomes are used primarily in toilet powders and for flavoring wines. For perfumery the products of *I. pallida* are preferred. Orris cultivated in and exported from Morocco, India and China is *I. germanica*.

Tuscan production of dried rhizomes reached a peak of 2,100 tons in 1914 and fell to 245 tons in 1939; French production has never surpassed 70 tons annually.

The horizontal rhizomes of orris are usually harvested from June to August of the third year after planting, eight to twelve tons per hectare. Those that have grown four or five years and consequently have become too hard through lignification to be peeled, are cut lengthwise into three parts, washed and then dried in the sun six or seven days. Younger rhizomes are peeled, washed in running water 12 to 14 hours and then dried in the open air 30 to 40 days, or in an oven. Sometimes the rhizomes are bleached with sulphur dioxide, particularly those to be used for comforters for teething babies.

Fresh orris rhizomes have an odor suggestive of the potato, and the fine violet odor develops slowly after harvesting, sometimes attaining its maximum only after several years. During this period the rhizomes must be stored and protected against insects and microorganisms.

The rhizomes are then finely ground and the perfume extracted either by steam distillation or by a volatile solvent, *e.g.*, benzene or petroleum ether. One product of this technique is "orris butter" which at times has been adulterated with fractions of oil of carrot. (*Y. R. Naves, Givaudanian, Feb. 1947*).

Wattle in the U. S. In 1937 the United States used about $15 million worth of tannin, primarily in the leather tanning industry,

secondarily in the manufacture of medicines, inks and boiler-cleaning compounds. To obtain this amount about 150,000 tons of tannin extract, tan woods and tan barks, valued at more than $7 million, were imported; the remaining 250,000 tons were produced domestically. Quebracho wood [*Schinopsis Lorentzii*], from Argentine and Brazil, was the principal source of tannin that year, 175,000 tons being used; chestnut wood [*Castanea dendata*] from the eastern United States was second, 123,000 tons; mangrove bark [*Rhizophora Mangle*, from East Africa, the East Indies and Central America] third, 21,750 tons; myrobolan nuts [unripe fruits of two Indian trees, *Terminalia chebula* and *T. Bellerica*] fourth, 18,500 tons; and wattle bark [*Acacia* spp.] fifth, with 15,250 tons. Other sources in the order of their importance were valonia [acorn cups of *Quercus Aegilops* from Asia Minor and Greece], spruce bark [*Picea* sp.], oak bark [*Quercus* spp.], hemlock bark [*Tsuga canadensis*], gambier [leaves of *Uncaria Gambir* in the Orient] and sumac [*Rhus* spp.].

In 1945 the United States used over 290,000 tons of quebracho wood, the most important source of tannin, and nearly 73,000 tons of wattle bark. Chestnut wood, the most important domestic source, has come from blight-infected and blight-killed trees, but in 10 or 15 years the supply is expected to be exhausted, since the blight prevents successful natural reproduction or planting operations. It already has been drastically curtailed and the result has been an increased demand for wattle bark to five times the quantity in 1940. This bark has come from plantations of black wattle (*Acacia decurrens* var. *normalis*) and green wattle (var. *mollis*) in Australia, South Africa and East Africa.

In an effort to diminish this dependence of the American tanning industry on foreign sources of wattle, a project was started in California in 1946 to establish a wattle industry there. The work is under the direction of the Drug and Oil Plant Division of the State Department of Education and was stimulated by an appropriation of $110,000 by a special session of the State Legislature in 1946 to extend the activities of that Division. Landowners are being encouraged to plant the trees, and within ten years, it is hoped, at least 375,000 acres of black wattle will be planted, a million acres within 20 years. "The immediate project contemplates maturing not less than 37,500 acres of wattle per year to yield 325,600 tons of wattle bark for conversion into tannin extract for the domestic trade".

Seed for the project has been obtained from the widely distributed trees of both varieties along highways and in parks of the State, some of them planted more than 50 years ago for study of their economic and ornamental value. At present the project is in the nursery-seedling stage and it is hoped that the trees will yield a crop in 7 to 13 years.

Wattle, rather than other sources of tannin, has been chosen for this work because it matures in that period, whereas tanbark oak [*Lithocarpus densiflora*] needs 50 years and quebracho 150 years. In Australia the bark of the two varieties contains about 35% tannin, and in California it has yielded 48%. California tanbark contains about 16%. It is hoped that these two sources may eventually replace the fast disappearing chestnut wood and supplement the imports of quebracho.

In South Africa wattle bark is commercially converted into a solid extract containing about 63% tannin, and the spent bark is valued in making wrapping paper pulp. This utilization suggests the possibility of replacing our annual imports (more than 6¼ million tons in 1937) of pulpwood paper pulp by the spent wattle bark of domestic production.

It is estimated that the total value of the annual harvest from the wattle project, including byproducts, should be over $38½ million. Byproducts might include, not only paper pulp, but also mine props, fence posts and railroad ties; veneer for market baskets; charcoal, methanol, acetone and pyroligneous acid through destructive distillation; and gum for use in adhesives. The investment in extractor manufactories and pulping mills necessary to process the contemplated 37,500 plantation acres of wattle trees per year would be in the neighborhood of $100 million.

In Brazil 30,000 acres of the two varieties have been planted in the last five years in an attempt to give that country a domestic source of tannin. (*H. Kegley, Hide & Leather & Shoes, as reprinted in Chemurgic Digest 6(4): 76. 1947*).

Asparagine and Glutamine. Asparagine, glutamine and isocritic acid are three rare chemicals produced by certain plants, the first two of which already have utilitarian value.

Asparagine is a preferred source of nitrogen in the culture of tubercle bacilli for the commercial production of tuberculin which is used in hypodermic injections as a test for tuberculosis. It is a constituent of asparagus stalks, up to 22% of their dry weight, but maximum amounts occur in the seeds of lupines. "Thus *Lupinus albus,* grown in Europe, Africa and South America, and *L. angustifolius,* a plant of the Mediterranean region grown in Florida for its seed, are excellent sources for the preparation of asparagine. One hundred pounds of either species will yield from 10 to 16 pounds of pure asparagine on etiolation. To produce asparagine, the seeds are spread fairly thickly on wire mesh trays or baskets and placed in a dark chamber supplied with a continuous fine spray of water. Germination begins in 24 to 48 hours and, after from 12 to 20 days, the huge mass of colorless tissue is harvested, ground, and the tissue juices pressed out. The pale yellow solution is concentrated *in vacuo* until crystals begin to separate. After being cooled the asparagine is filtered off and purified by recrystallization from water. It is then ready to use in the preparation of many media on which bacteria and fungi are grown".

Glutamine is essential in laboratory culture of certain haemolytic, or blood-destroying, streptococci. It is an important constituent of animal blood, liver, kidney and brain, but is best obtained from plant sources. Squash and sunflower seedlings yield up to 4% by weight of the dry seeds, and beet roots are also an excellent source. (*G. W. Pucher, Jour. N. Y. Bot. Gard. 48: 77. 1947*).

Vanilla on Dominica. More than a million pounds of vanilla beans are annually imported into the United States from various parts of the world. They are today valued at about $8 per pound and are used mainly in flavoring ice cream at a cost of only about ten cents per gallon. The island of Dominica in the British West Indies is one of the largest producers of the beans in the western hemisphere, exporting 50,000 pounds of cured beans in 1945.

In the rain-forest mountains of Dominica the vanilla-producing terrestrial orchid plants, *Vanilla planifolia,* are cultivated almost entirely by negro peasants, and always on a small scale, sometimes only one plant. The plants may climb 40 feet high on trees supporting them, and then hang down from the tops. An old plant may produce 30 pounds of green beans in one season; more often, one pound is a normal annual crop per plant, which when cured yields about three ounces of vanilla, worth about one dollar to the peasant.

Vanilla pods will not develop without pollination of the small yellow flowers, and natural pollination, even in Mexico, the original home of the species, is rare. Hand pollination, therefore, is necessary and is performed usually with a small piece of wood or a safety pin. Only the quicker self-pollination is practised, and the flowers wilt almost immediately after being treated. An experienced negro can pollinate more than 600 flowers between sunrise and noon. In a few months thereafter the pods attain a length of eight inches or more but do not ripen until eight or nine months later.

The beans, after being harvested, are cured by being scalded in hot water for a few seconds, then placed in small boxes covered with woolen blankets for a day or two to sweat from the heat generated by their own enzyme activity, next placed in the sun until they reach about one-fifth of their original weight, and finally conditioned in boxes for several months. There is no aroma without all this treatment. (*L. H. Narodny, Jour. N. Y. Bot. Garden 48: 33. 1947*).

Yawa. Yawa, *Vigna sinensis* var. *textilis,* a variety of the common cowpea, is cultivated in Nigeria as a source of fiber for making ropes, twines and fishing nets. The fiber, extracted from the stems after the beans have been gathered, has recently been found to be a promising substitute for manila hemp in paper making. (*Synthetics, as reported in Chemurgic Digest 6(8): 139. 1947*).

Economic Plants of Truk. The native Micronesians of the 40 square miles of land in the Truk archipelago of the northwestern

Pacific subsist primarily on tree crops, secondly on root crops and thirdly on other crops.

Among the tree crops the coconut palm [*Cocos nucifera*] is the dominant species; the breadfruit [*Artocarpus communis*] the subdominant but the more important to the natives.

Coconut palms, known locally as "nü", are abundant everywhere, in pure or mixed stands, and recently covered 10,500 acres as a result of extensive plantings encouraged by the former German and Japanese administrators in the islands to meet the ever growing demand for copra in the export trade. The natives utilize the trees in numerous ways. "They drink the water of the young nuts. Especially on the coral islands, they bleed unopened spathes and collect the sap, which is rich in sugar and vitamin B, and is usually consumed unfermented. The jelly-like meat of very young coconuts is easily digested, and mothers use the flesh as supplementary food for their babies. The flabby white meat of drinking nuts is eaten without any ill effects, since it is not so rich as the meat of a ripe nut. The latter is used as food either grated or in the form of coconut milk pressed out of the grated meat. This coconut milk is very rich in fat and is usually poured over starchy dishes prepared from fresh or preserved breadfruit or taro.

"The wood of old palms is used for construction purposes. The leaves supply thatch and material for basket weaving. The shells serve as cups and ladles, and the fiber of the husk is used on the low islands around Truk for the making of cord and rope".

"The breadfruit tree ["mai"] is not only very important as a source of starchy food but also as a source of valuable timber used in the construction of houses, the making of bowls, and the building of outrigger canoes. The trees attain a height of 40 to 50 feet. The leaves, which are serrated and may be 1.5 feet long, are used to wrap food and other things. The fruit is about 6 to 8 inches in diameter and has a rough, yellow-green skin. The sticky sap is utilized for the caulking of boats. Mixed with colored earth it is used to paint boats. . . . Truk may be considered one of the centers of breadfruit culture. Here scores of varieties, both seedless and seedy, are in cultivation. West and east in the Carolines and in the Marianas, the breadfruit is more nearly a secondary food.

"The trees are propagated from roots or cuttings. The period during which fresh breadfruit is available has been prolonged by development of varieties that mature both early and late so that fresh breadfruit is available in varying quantities during at least 6 months of the year. The main harvest season, 'ras', falls into a period from July to September.

"Fresh breadfruit is either baked and eaten much as a baked potato, or it is steamed and pounded with pounders, 'üsüs', made of coral or basalt, on pounding boards, 'nif'. The pounded breadfruit has the consistency of a rather stiff dough or pudding, 'kon', which is shaped into round or oval loaves. These loaves are wrapped into large taro, banana, or breadfruit leaves. There are, of course, many other ways of preparing breadfruit. On special occasions the pounded breadfruit, 'kon en mai', is rolled into small balls, or cut into little cubes, put into a bowl, and covered with coconut milk. This is generally considered a delicacy.

"During the main harvest season every family stores its surplus breadfruit in pits, 'nas', where it is preserved by fermentation. The fermented breadfruit is called 'mar'. There are three sizes of pits. The smallest has a diameter of 3 to 4 feet and is about 3 feet deep. The largest is about three times as large. Only in years with an especially abundant harvest do the Truk peasants fill the large-sized pits in addition to the small- and medium-sized ones".

Breadfruit recently covered 7,600 acres in the islands, and along with coconuts accounted for 96% of the crop area.

"Of lesser importance [as tree crops] are bananas [*Musa paradisiaca* subsp. *sapientum*], pandanus [*Pandanus tectorius, P. utilis*], papaya [*Carica Papaya*], lime [*Citrus aurantifolia*] and sour-orange [*Citrus Aurantium*], soursop [*Annona muricata*], and mango [*Mangifera indica*] trees. The last-mentioned was introduced into Truk by American missionaries in the 1880's.

"Before cotton cloth became available, the people of Truk obtained their fibers from either *Hibiscus tiliaceus* L. or a banana variety grown especially for this purpose. The Japanese encouraged the raising of Hibiscus

and exported the decorticated bast fiber to Japan. The wood of this tree is of great value in the construction of houses and canoes".

Among the root crops of Truk are:

Cyrtosperma chamissonis (Schott) Merr. The leading root crop of the Truk Islanders, raised in fresh-water swamps or marshes in depressions between the volcanic uplands and the sandy coasts. A large taro-like plant up to 12 feet tall, known as "puna".

Colocasia esculenta (L.) Schott. Taro, known locally as "oni", "grows from 3 to 5 feet high. . . . It has a large edible corm, and its young leaves make an excellent vegetable when cooked long enough to remove the calcium oxalate crystals". There are a great many races of both *Cyrtosperma* and *Colocasia*, and all kinds of taro recently accounted for 3% of the crop area.

Alocasia macrorrhiza (L.) Schott. Elephant ear, known locally as "kä" in the cultivated form and as "munu" in a wild variety, also is taro-like but is cultivated only on dry land. "Its tuber is much larger than that of taro and is considered definitely inferior to the other two aroids, because even when cooked it still irritates the mouth".

Tacca leontopetaloides (L.) Kuntze. Arrowroot, known locally as "mok-mok", "grows everywhere spontaneously. The tubers are dug when the plant dries up in October and are cleaned and grated. The meal is placed on a mat coarse enough to retain the fibrous gratings. Then water is poured over the meal, and the starch is washed out. Dishes made of arrowroot starch are considered a delicacy and may be prepared for babies or sick persons, but the amount of labor involved and the small quantity of starch obtained from a single plant may explain why arrowroot is not an important source of food supply in Truk".

To the above root crops the Japanese added sweet potatoes [*Ipomoea Batatas*] and manioc or cassava [*Manihot esculenta*] which they raised on a large scale during the war but which are not popular with the natives. Yams (*Dioscorea* sp.) are of little or no economic importance in Truk but form one of the staples in Ponape and Kusaie.

The third group of crops, raised usually in small gardens, include sugarcane which is chewed for its juice, pineapple, tobacco, red pepper, melons, pumpkins, squashes, cucumbers and a few others, mostly introduced by the Japanese. Rice, corn and sorghum were also introduced before and during the war but have since been discontinued, and the Truk peasants today practice a grainless agriculture. (*K. J. Pelzer, Foreign Agriculture 11(6): 74. 1947*).

Peanut Protein Fiber. In England there has been semi-commercial production of a protein synthetic fiber made from peanuts, known under the trade name Ardil. All other types of protein-base synthetic fibers have so far been produced only on a laboratory or small pilot-plant scale. At the Northern Regional Research Laboratory, Peoria, Ill., investigations have been conducted on such use of zein, or corn protein, and at the Southern Regional Research Laboratory, New Orleans, research is under way with regard to similar use of peanut protein, as well as upon its employment in adhesives, sizes, paper coatings, cold water paints, *etc.* Similar products can be made from soybean protein.

Technological problems involved in the successful production of peanut protein include decolorizing or removing the skins and obtaining oil-free meal. In the latter respect solvent extraction of the oil is more efficient than the commonly used hydraulic press or screw press which leave too much residual oil in the meal and involve temperatures that are destructive to the proteins. Solvent-extracted peanut meal contains about 50% protein. After extraction of the protein the residue can be used as feed, and the accompanying supernatant liquor can be converted into an excellent medium for yeast propagation in the production of feed yeasts.

"The preparation of the protein itself is simple, consisting of extraction of the protein from the oil-free meal by means of dilute alkali, and precipitation of the extracted protein followed by drying", all under carefully controlled conditions, especially with regard to temperature and pH.

"Essentially, the production of fibers from peanut protein involves the following steps: (1) Dispersion of the peanut protein in strong alkali to form a spinning solution; (2) Extrusion of the spinning solution through a spinneret into an acid coagulating bath; and (3) Stretching and chemically

treating the fibers to give them the desired properties". (Further details in the article). Peanut protein fiber produced in this manner at the Southern Regional Research Laboratory has been given the name Sarelon.

From the standpoint of economics, "all of the present and potential sources of industrial protein in this country have one feature in common, namely, the protein available from these sources is obviously only from byproducts whose value is much less than that of the principal products. For this reason, the potential supply of industrial protein from any one source is largely limited by the demand for the principal products. Furthermore, users of industrial protein will have to compete either directly or indirectly with consumers of these products from which the protein is obtained. Lastly, the protein fiber industry will have to compete directly with other users of industrial protein, of which there are many".

Casein, produced from skimmed milk in the United States up to 25 thousand tons annually before the war, is the largest present source of protein used in the commercial manufacture of fibers. However, "disregarding any technical problems involved, the three largest potential sources of industrial protein in this country, based on present production rates, are the vegetable seeds, soybeans, cottonseed, and flaxseed, in that order". The protein content of these seeds after the oil, the principal product, is expressed ranges from about 35% in flaxseed to about 40% in the others. In recent years the annual production of them in the United States has amounted to about 3½ million tons of soybean cake and meal, slightly less than 2 million tons of cottonseed cake and meal, and about 800 thousand tons of linseed cake and meal.

Another large potential source of industrial protein is the annual average of about 200 thousand tons of peanuts crushed for oil, leaving about 100 thousand tons of cake and meal. (*W. M. Scott, Chemurgic Digest 6(12): 192. 1947*).

Bamboo Pulp. Bamboo pulp has been used in India for 25 years in the manufacture of a variety of papers, including high-class book and writing papers. At present about 80,000 tons of such pulp are annually used there for this purpose. It has also been used there for Kraft paper, and, in admixture with mechanical pulp, is suitable for newsprint.

Bamboo has not hitherto entered into the manufacture of rayon, but a company has recently been formed in Travancore, India, for such manufacture in addition to the production of paper. These operations will depend upon the enormous reserves of bamboo in India, Burma, Malaysia, Kenya, Rhodesia and British Guiana. Principal among these sources is Eetta bamboo, *Ochlandra travancorica,* in the forests of North Travancore. "In Lower Burma alone the bamboo forests are stated to cover 2,400,000 acres, capable of yielding 1¾ million tons of dry stems each year, and that on the slopes of Mt. Kenya there are estimated to be at least 600,000 acres of *Arundinaria alpina,* a bamboo which grows to a height of 60 feet and has a basal diameter of 5 inches.

"There are about 550 different species of bamboo varying in size from small bamboos about 1 foot long to giants 120 feet tall with a diameter of 8 inches. Most bamboos are perennial, having branching rhizomes which send up culms. The first culms are short and small in diameter but with each flush of growth the new culms are longer and bigger, so that, although young culms contain less resistant lignin, for regeneration purposes it is advisable to cut only culms which are six to eight years old, to enable the younger culms to develop more fully. Cutting can be continued for thirty to sixty years until the bamboo flowers, when the plant dies. Since all the members of the same species of bamboo in the same area flower at the same time, regardless of their age, it is advisable to have more than one species in the area to ensure continuous supplies. During the seeding cycle the plant reproduces by means of rhizomes, so that there is a continual supply of stems throughout the cycle. Propagation either by seeds or by rhizomes is fairly simple. On account of its quick growth, bamboo tends to smother other plants in the area and there are, consequently, often huge stands of pure bamboo occurring, an important factor as regards the cost of cutting. In view of its quicker rate of regeneration and the enormous reserves available annually it is from the supply point of view better placed even than wood. Although native to the humid

regions of equatorial and sub-tropical latitudes, the range of bamboos is wide, and they have been planted for ornamental and other purposes in many countries outside their usual range, including this country [England], where about 22 acres in Cornwall are planted under bamboo and from which about 6,000,000 canes up to 30 feet long were harvested last year by the British Bamboo Company". (*Anon., Fibres 8(3): 82. 1947*).

Guar. "During the past 10 years, vegetable gums have found a wide variety of uses in food, paper and textile products. They serve, for example, as stabilizing and thickening agents in salad dressings, ice cream mixes, bakery products and other foods. Textile manufacturers use them in warp sizes, printing pastes and finishes, and papermakers have found them a valuable aid in sizing and in the hydration of cellulose fibers.

"At present, locust bean flour, obtained from the seed of a pod-bearing Mediterranean tree [*Ceratonia Siliqua*], is the most widely used mannogalactan gum, but, since it must be imported, supplies are relatively uncertain, and commercial users have been looking for a satisfactory domestic source of vegetable gum materials.

"Although there are many potential sources in the United States, none of them now represent commercially developed farm crops. Guar, which was introduced into this country by the United States Department of Agriculture as a possible green manure and cover crop, is the only one which shows promise of providing a consistent, easily regulated supply of gum-containing seed. Since it is an annual and can be both planted and harvested with standard agricultural equipment, it can be worked into the rotation plans of farmers in qualified areas of this country.

"During the past four years the General Mills Research Laboratories have been studying this plant as a potential commercial source of vegetable gum and have been developing milling methods to separate the gum from other portions of the seed. The Laboratories have also sponsored cultivation of the plant by farmers and ranchers on irrigated lands in southern Arizona and southern eastern California.

"Guar, *Cyamopsis tetragonoloba,* is an annual, summer growing, drought-resistant, soil-improving legume from India where it has long been grown for human food and as cattle fodder. It grows three to six feet tall, in many varieties, with clusters of bean-like pods, each of which contains six to nine pebble-shaped seeds.

"The General Mills Laboratories have been supplementing their commercial growing program in the Southwest with experimental plantings conducted in cooperation with the University of Arizona at its Mesa Experiment Station". (*J. A. Esser, Progress Thru Research, General Mills, Inc., as reprinted in Chemurgic Digest 6(15): 229. 1947*).

Bamboo in Ecuador. Bamboos are abundant, well known and commercially important in the lowlands of Ecuador where *Guadua angustifolia* is the principal species. In the highlands of the country, however, between 5,000 and 11,000 feet elevation, are many other kinds of bamboo which are of importance to the local population. This is a region where ample to heavy rainfall is more or less well distributed throughout the year and where the predominant bamboo species belong to the genus *Chusquea* and occur in relatively pure stands. They are, for the most part, small to medium in stature, one to two inches in diameter, and all have solid culms, low in strength and durability.

The genus is locally known as "suro" and "moya", and the culms are used in house construction, serving as a support for mud plaster on walls, or as sheathings to support tiles or thatch on roofs. Strips of "suro" split from the culms are woven into hats and usually handle-less baskets of great variety in size, shape and color.

The heavier culms of another group of *Chusquea*, known collectively as "moya", are used in ladders, fences, roof timbers and to a limited extent as vaulting poles and sparring staves; in earlier days probably they were the material of elaborate banister spindles.

Another generic group of bamboo in the highlands of Ecuador is known as "tunda" and a third as "tundilla", the species within them having certain local uses. One kind with hollow culms two inches wide and internodes five feet long, is made into "bocinas" or "vocinas", a form of trumpet used to sum-

mon workers and for other purposes of similar nature.

Thin nodeless strips of the tough outer layer of the long internodes of other bamboos are woven by the Indians into flexible baskets, and the children make blow guns and shepherd's pipes from them. Of the "tundilla" type it is reported that "their thin-walled relatively fragile internodes make fire-blowing tubes, *fucuneras,* an inexpensive and effective substitute for the bellows as a means of encouraging a reluctant flame. This bamboo is considered to have potentialities as a source of broom fiber and material for weaving, matting and making shades for seedbeds and delicate young nursery stock such as cinchona plants".

Two oriental species of bamboo have been introduced into the Ecuadorian highlands—*Phyllostachys aurea* in 1927 and *P. bambusoides* in 1937—but the plantings are still experimental. (*F. A. McClure, Agriculture in the Americas 6: 164. 1946*).

Soybeans. In the United States soybeans [*Glycine Soja*] are grown as a crop for a great variety of uses in plastics and other manufactured products, and to be fed as hay to cattle. Relatively few are used here as human food, principally because of their bitter taste and failure to cook soft. In eastern Asia, however, and also in Surinam, whence this article came, the beans are planted for seed production alone, chiefly for human consumption. In those regions the above-noted shortcomings of the beans are overcome by fermentation through the agency of fungi, and some of the food products thus and otherwise produced are as follows:

TOKOLAN or TAOGÉ:—Sprouted soybeans used as an ingredient of every "rijst-tafel" menu in the Netherlands East Indies. Also in the markets of Paramaribo.

SOY MILK:—Made by soaking the yellow variety of beans in water, then grinding them in crude hand-operated stone mills, next diluting with water and then filtering through cheesecloth. Used like cow's milk in China. Very limited use as such in the United States or in the East Indies.

TAOHOO or TAHOO:—The second most common soybean product eaten in the Netherlands East Indies. In China it is the most important soy product. It is a cheese made by stirring into 120 liters of hot soy milk, one liter of a 12% saline solution and 15 cubic centimeters of 80% acetic acid. The resultant curd is subsequently dried into cheese under pressure on frames covered with cheesecloth. The cheese is then cut into smaller pieces and sold as such or is first baked in lard or oil.

Of the two waste products resulting from this process, the filter-residue and the whey, the first may be fed to pigs as a concentrate; the second is useless and is discarded.

"In China 50 grams of calcinated plaster of Paris is used to start the coagulation of the same quantity of soy milk. The whey from this may be used in agriculture as a thin liquid manure, whereas whey containing salt will be harmful for this purpose in the long run".

"Taohoo is occasionally manufactured in the United States for the Chinese restaurant trade".

TAOTJO:—A fermented paste-like condiment prepared by mixing boiled soybeans with roasted meal of wheat or glutinous rice and wrapping the mass in hibiscus leaves which commonly harbor the fungus *Aspergillus Oryzae,* necessary for the ensuing fermentation. "After two or three days the moldy mass is brought into brine and kept for several weeks. Palm sugar is added at intervals. Taotjo must be made in the dry season, because every day it has to be brought outside into sun and air for hours. This dish is eaten in the East with the 'rijst-tafel'. In Surinam it is not manufactured at all".

KETJAP:—This, "the well known soy sauce, is made all over East Asia and even here in Surinam. To manufacture ketjap the soybeans are boiled and after cooling are wrapped in hibiscus leaves, just as with taotjo, but without mixing in the roasted meal. After fermenting for two or three days the mass is brought into brine, as with taotjo. Every day for one to several months it is exposed to the sun. At intervals a little palm sugar is added. Then the fluid is filtered and the residue cooked several times with fresh water to extract all the soluble parts. The fluid is then concentrated by slow boiling. Spices and other piquant materials are added, according to the *specialité de la maison.* These may include galangal, ginger,

cloves, Jew's ear fungus, and dried and ground fish and chicken meat".

TAOKOAN:—A yellow cheese made in China by impregnating taohoo with turmeric and reducing the water content by heavier pressing.

TEMPE:—This is the principal food made from soybeans in tropical countries where the beans are grown for human consumption and not for conversion into manufactured articles. It is unknown in China and other cooler regions, where the beans also constitute an important part of the human diet, but in the Netherlands East Indies it is definitely a staple food. This restriction to tropical regions results from the dependence of the preparation of tempe on the presence of a particular fungus, *Rhizopus Oryzae,* which thrives only in those areas and is necessary for fermentation of the boiled beans. Millions of people daily consume the preparation in the Oriental tropics, and migrants from those regions have imported it elsewhere in the world, as have a few Javanese settlers in Surinam.

Preparation of the material, as carried out by a Javanese woman in Surinam who daily prepares it for sale, involves the following successive steps: (*a*) boiling about six pounds of yellow soybeans one hour in about four times as much water, whereby they swell to two and one-half times their original volume; (*b*) removing the seedcoats, after having cooled, by treading them with feet or kneading them by hand; (*c*) just covering them with water and allowing them to ferment 24 hours; (*d*) boiling them again in the same water to stop fermentation; (*e*) spreading the beans on a pandanus mat to cool; (*f*) mixing broken pieces of a previously made tempe cake with every five pounds of newly fermented beans and removing the pieces about two hours later; (*g*) remixing the soft inoculated beans, wrapping a handful each of them in two or three layers of large monocotyledonous leaves and tying the packages with raffia or rice stalk; (*h*) cutting the tempe cakes 48 hours later, when they are covered with a luxuriant white fungus growth, into thin strips to be fried in coconut-oil or butter and then eaten.

Large tempe cakes, a foot in diameter, are also made, especially for festive occasions, by placing the boiled, fermented and inoculated beans between three layers of monocotyledonous leaves in flat baskets. Such cakes may have 25 to 30 times as much bean mixture as do the smaller packages described above. The fungus never penetrates into the tissues of the seed lobes but remains restricted to the spaces between the beans and to the surface of the cakes. Tempe several days old may be poisonous.

The vital role that is played in this preparation by the fungus, provided by adding the pieces of previously made tempe, is impressively brought out by the following incidents. Previous to the recent world war tempe was prepared in New Guinea with soybeans imported from Java, but when such imports stopped, tempe-making ceased in New Guinea, the essential fungus was lost in the island, and for two years the people there were without this essential food. Soybeans were then sent by the U. S. Government to feed the Europeans and Indonesians living there, but without the fungus the beans were unpalatable to people of their eating habits. To remedy this situation the Economic, Financial and Shipping Mission of the Kingdom of the Netherlands in New York asked the author of this article in January, 1945, to send inoculation material of the fungus from South America to the Orient. The request was carried out by airplane from Paramaribo in a little more than a week, and in the author's own words, "Now this pleasant food is daily consumed in New Guinea, made from U. S. soybeans and cultures of the Surinam *Rhizopus*". (*G. Stahel, Jour. N. Y. Bot. Garden 47: 261, 285. 1946*).

Tree Rings. A study of tree rings in North Dakota has served the archaeological purpose of dating the timber remains from certain long-abandoned Indian settlements of the State and has also contributed to precipitation records.

In this work a so-called "master stump" of burr oak was located about six miles northwest of Bismark. The tree was cut in 1940, at which time it was three to four feet in cross-section and showed 375 rings. Two neighboring oaks, one about 50 years old, the other about 120 years, were cut in 1945. The occurrence of dry, wet and average years during the lives of these three trees, as indicated by the widths of their annual rings,

was plotted on cross-section paper. In addition, plots were made of weather bureau precipitation records for the area, of cross-sections from other trees, and of another "master oak" studied elsewhere. Six plottings were thus made, and "all six were found to be in agreement in about 40 years out of 110 years compared and all six were in complete agreement in all but one case in 42 other years. This makes a total of slightly more than 80 years of reasonable agreement among the six charts used".

Some 60 cross-sections were then cut from burr oak and *Juniperus scopulorum* logs and posts from old Indian villages of the State, preserved by the North Dakota State Historical Society. The annual rings in these fragments were matched with rings of similar width from the "master stump", and "after the youngest site had been definitely linked up with the master chart and pretty well dated, came the problem of the still older sites. It was soon found that the fragments from some of them coordinated with rings found in the earlier periods of growth in some of the larger fragments from the Ft. Lincoln site. In turn it was found that pieces from still older sites matched up with the early portions of fragments from the site which showed earlier dates than Ft. Lincoln. By this method it was possible to carry the ring calendar considerably farther back than the earliest date of the master chart. In this way, from the oldest fragments that were on hand the ring calendar was completed back to the year 1406, that being the sprouting date of the oldest tree cut in the building of the oldest site from which material was available. Thus there is available a continuous record of precipitation over a period of five hundred and thirty six years. There is reasonable hope that usable material from sites of apparently still greater age than those studied, sites which from fairly good evidence are considerably older than any from which material is at present available, may be excavated as opportunity offers".

These studies concerned areas once occupied principally by the Mandan Indians, and with respect to one of the sites considered it is reported that "it would appear that building started at the Huff site some 455 years ago from timber which started to grow as early as five hundred and forty years ago. It would appear that Mandan people occupied the area at a much earlier date than had previously been supposed. It is to be hoped that timbers from some of the earlier Middle period sites and the Archaic sites may in time be found. Meantime we have the story of a successful occupation of this area along the Missouri by an agricultural population for a period many times longer than that of our own white race".

"It would seem probable that material from the very large number of sites very evidently older than the one at Huff, when available, will carry the occupancy of the region by the Mandan people very nearly two hundred years farther back to a date probably between 1200 and 1300.

"Material from a hundred or more other sites should be collected as soon as possible before it further deteriorates. It is obvious that only a start has been made in tree ring study. However, the basic master chart is complete for five hundred and forty years. Its working out and construction was a slow, laborious, time consuming piece of work which need not be done again. Consequently results from additional material acquired will be much quicker to compare and assign to their proper dates.

"The history obtained from the tree rings seems to carry considerable comfort to the present inhabitants of the region. If human beings have found the area well enough suited for some seven hundred years to be a home from which there was no high incentive to move in search of better surroundings, and since there has obviously been no change in rainfall conditions for a period of some five hundred and forty years, the present dwellers in the region may well look forward to centuries of continued occupancy of the region by a reasonably prosperous population. And furthermore as the residents become more familiar with the region and its conditions the task of so regulating their activities as to better co-ordinate with climatic conditions should serve to definitely increase their prosperity".

In addition to assisting in the dating of the Mandan settlements, the tree rings also gave a continuous precipitation record covering 534 years. Interpretation of these rings in terms of rainfall showed for the period 241 wet years, 238 dry years and 55 average

years. The value attached to these findings is thus stated: "Continued study of tree rings from timbers taken in different parts of the region will serve to steadily increase our long time knowledge of conditions in the various sections. Further study of the data given above may serve in time to give determinations of relationships between wet and dry periods and to discover some rhythm in their recurrence which is not so far apparent. The data given would seem to have some bearing on the much discussed problem of irrigation. It seems to show that more than half of the years are wet enough to discourage attempts at irrigation. In other words, the region is marginal as far as irrigation is concerned. Previous experience has shown that as a dry period fades out, interest in irrigation fades with it. Conditions are decidedly different from those in the more arid territory further west where irrigation is practically an annual necessity. Therefore, it would seem that, though irrigation would have great definite value to the area, it must be based on a system which will not carry a high overhead in favorable years, and the elements of which may be kept in a sort of dormant state, to be brought into use again as the dry periods return after the wet ones". (*G. F. Will, No. Dak. Agr. Exp. Sta., Bull. 338. 1946*).

Essential Oils. Southern France, Italy and Spain have long been the traditional sources of essential oils for American manufactured perfumes, cosmetics, soaps, foods and medicines. When World War II cut off three-quarters of this foreign supply, domestic sources of the oils had to be relied upon, and by 1946 the annual value of essential oils from home sources was estimated at $20,000,000. "In 1939 the value of essential oils distilled in the United States from both domestic and imported basic materials was only $9,800,000".

The record of domestic production is as follows:

Oil of sweet orange [*Citrus sinensis*]. Home production supplied more than half the domestic need in 1937; in more recent years it has met the entire demand. Florida furnishes about 250,000 pounds annually now, California 500,000 pounds. The oil is obtained mostly by cold-pressing; a little on the West Coast by distillation of the cold-press residue.

Oil of lemon [*Citrus limoni*]. California met two-thirds of demand in 1937; meets entire demand today, and has furnished up to 1,700,000 pounds in one year; cold pressed.

Oil of lime [*Citrus aurantifolia*]. Limited to Florida keys; 1,060 pounds produced in 1943–1944, only 375 pounds in 1944–1945.

Oil of grapefruit [*Citrus maxima* var. *uvacarpa*]. Mostly from Florida, about 50,000 pounds; cold pressing.

The foregoing citrus oils enter into the manufacture of lemon drops, orange "pop", gelatine desserts, bakery goods, powdered cornstarch pudding, lotions and perfume bouquets; and orange oil goes also into flavoring tobacco.

Oil of Thuja [*Thuja occidentalis*]. Known also as "cedarleaf oil"; 75,000 to 100,000 pounds distilled in 1944 from leaves of white cedar in northern New York and Vermont; much goes into perfumes.

Oil of cedarwood [*Juniperus virginiana*]. From the red cedars of Florida, the Carolinas, Georgia, Tennessee and Virginia; distilled principally from chips of red-core wood, some from waste of pencil manufacture; 200,000 pounds produced annually meets domestic needs in perfumes, soaps, mothballs, fly sprays and shoe polish.

Oil of pine [*Pinus palustris* mostly]. Obtained from the turpentine industry, using southern pines, which yield also terpineol, a synthetic lilac. Pine oil goes into insecticides and medicines, terpineol into perfumes and soaps.

Oil of sassafras [*Sassafras albidum*]. About 25,000 pounds produced annually in homemade stills "from Maine to Florida and in the hills of Kentucky and the rolling country of Ohio". The oil goes into rootbeer, sarsaparilla, candies, chewing gums, mouthwashes, toothpastes, soaps and perfumes.

Oil of sweet birch [*Betula lenta*]. 10,000 pounds were produced in 1944 from Pennsylvania and North Carolina; uses are similar to those of oil of sassafras.

Oils of spruce [*Picea* sp.] and hemlock [*Tsuga canadensis*]. 50,000 pounds produced in 1944 "from the farming and lumbering areas of the region from the Great Lakes

east to the Atlantic Coast and south to Virginia"; used in perfumes.

Oil of peppermint. "Kalamazoo, Michigan, has the largest peppermint distillery in the world. The principal variety of peppermint in the United States is *Mentha piperita,* grown for the most part on the black, velvet muckland of northern Indiana and southern Michigan. Oregon and Washington also contribute to the domestic supplies of peppermint oil. Some successful attempts have been made to raise the Japanese type, *Mentha arvensis,* in California.

"Production of peppermint oil in 1945 is estimated to have been 1,603,000 pounds, an increase of 31 percent over the 1944 figure. The area under cultivation in 1945 totaled 47,660 acres, the largest proportion—19,500 acres—being in Indiana. Some 42,880 acres were planted in Indiana".

Oil of spearmint. In 1945, 312,000 pounds were produced on the 8,600 acres devoted to the crop in Michigan and Indiana. The oil is distilled from the leaves and flowering tops of *Mentha viridis* and *M. spicata,* and is used to flavor chewing gums, dentifrices, medicines and candies.

Oil of wintergreen [*Gaultheria procumbens*]. "Grown chiefly in New England, Pennsylvania, and North Carolina, wintergreen is harvested by farm families incidental to the main crops of the fields, and is distilled in crude apparatus. The output ranges from 3,000 to 5,000 pounds a year".

The foregoing three oils are used to flavor mouthwashes, toothpastes, medicinals, candies, desserts, chewing gums, jellies, soft drinks, liqueurs and soaps. "Both peppermint and spearmint are cultivated crops, produced on a fairly regular annual basis".

Oil of wormseed [*Chenopodium ambrosioides* var. *anthelminticum*]. "About 97 percent of the world's commercial production of wormseed oil, distilled from the plant of the same name, centered on a 1,000 acres in the southern part of Carroll County, Maryland. The average yield aggregates 40,000 to 60,000 pounds a year. Wormseed oil, or chenopodium oil, is sold as an antiworm preparation".

Oil of wormwood. Distilled from an herb, *Artemisia Absinthium,* cultivated mainly in southern Michigan. It is used as a flavoring agent in cordials and as an ingredient in tonics. About 15,000 pounds are processed annually.

Oil of erigeron [*Erigeron canadensis*]. Distilled from wild plants in northern Indiana and southern Michigan. Used in medicinals and condiments.

Oil of tansy [*Tanacetum vulgare*]. Distilled from commercially raised plants in northern Indiana and southern Michigan. Used in medicinals and condiments.

Oil of dill [*Anethum graveolens*]. Used in preparing dill pickels and recently introduced as a crop into the Pacific Northwest.

Oil of lemongrass [*Cymbopogon citratus*]. Formerly imported from India, but in 1942, 1,500 acres of Florida's mucklands were turned to its production. Used to perfume soaps, bath salts and cosmetics, and is the sole source of synthetic violet (ionones).

Oil of pennyroyal [*Hedeoma pulegioides*]. Distilled in limited amounts on the east coast from Virginia to northern Alabama and used for scenting soaps.

Oils of roses [*Rosa* sp.], cherry laurel [*Prunus laurocerasus*], horsemint [*Monarda punctata*], goldenrod [*Solidago* sp.], *etc.* Experiments directed toward extracting volatile oils from these plants are being conducted in Texas.

Oils of Dalmation sage [*Salvia officinalis*], French marjoram [*Satureia Nepeta*], Spanish thyme [*Thymus vulgaris* and *T. Zyges*] and Italian lavender. Similar experiments on the production of these oils are under way in California. (*Marian D. Hall, Chemurgic Digest 5(16): 269. 1946*).